NAVAL ORDNANCE

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A TEXT-BOOK

PREPARED FOR THE USE OF THE MIDSHIPMEN OF THE UNITED STATES NAVAL ACADEMY

BY

OFFICERS OF THE UNITED STATES NAVY

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PREFACE

Recent developments in Ordnance and Gunnery have made it necessary to revise the text-book "Naval Ordnance," 1915.

The object sought in the present revision was twofold. The first was to eliminate incorrect or obsolete data and bring the text up to date. In this connection it was considered undesirable to describe numerous types or marks of guns, mounts, breech mechanisms, etc. One modern type was selected in each case and every effort made to cover its description clearly and completely. The second object sought was to make the book a complete treatise on the "Theory of Ordnance" in so far as that was possible under the limitations imposed. With that end in view the following subjects formerly published in separate books or pamphlets have been included in the text:

"The Elastic Strength of Guns," 1916, by Philip R. Alger, Professor of Mathematics, U. S. N.

"Graphic Representation of the Relation of Pressures and Shrinkages of Built-up Guns for the States of Action and Rest," by Lieut. Commander L. M. Nulton, U. S. N.

"Recoil and Recoil Brakes" (new material), by Mr. G. A. Chadwick, Chief Draughtsman, Bureau of Ordnance.

"Practical Interior Ballistics," a Bureau of Ordnance Pamphlet.

It was considered undesirable to include a treatise on "Exterior Ballistics" inasmuch as that subject is so satisfactorily dealt with in the present text-book "Ground Work of Practical Naval Gunnery."

The following officers were asked to contribute chapters to the book and grateful acknowledgment is made for the excellent material submitted by them:

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The major portion of the task of editing the various chapters and preparing the book for publication was performed by Commander F. D. Pryor, U. S. N., assisted by officers of the Department of Ordnance and Gunnery. These officers deserve great credit for their painstaking work.

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Commander, U. S. Navy.

U. S. NAVAL ACADEMY,
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CHAPTER I.

EXPLOSIVE REACTIONS.

Section I.—Explosive Substances.

1. **An explosive substance** may be defined as a chemical system which is capable, when subjected to a suitable initial impulse, of nearly instantaneous chemical decomposition or transformation, with evolution of heat and formation of decomposition products some of which are gaseous. An explosive reaction is always accompanied by a sudden rise of pressure due to the formation of gases and to their expansion by the heat liberated in the reaction.

2. Among explosive substances are included a wide range of mixtures and of homogeneous chemical compounds. In general the explosive reactions to which they give rise are characterized either by (a) an extremely rapid combustion, or by (b) a rearrangement of molecules which proceeds practically instantaneously.

In the explosives giving rise to reactions of the first of the above classes, oxygen is always present, with one or more combustible elements. The oxygen is supplied in such form as to permit the oxidation or combustion to proceed without support from outside sources. The reaction in these explosives is a true burning which proceeds from point to point throughout the explosive, accelerated by the heat and pressure produced. These explosives are therefore known as *burning* explosives, or as *progressive* or *low* explosives. Among the well-known explosives of this kind are black powder and the smokeless powders of various classes.

In those explosives giving rise to reactions of the second of the above classes, oxygen is nearly always present with combustible elements such as carbon and hydrogen, being usually held in the system in weak bonding radicals, most frequently in the NO_2 or nitro group. In these explosives the chemical arrangement is one of unstable equilibrium and the initial impulse brings about a breaking down of chemical bonds and a rearrangement of molecules which is so rapid that the evolution of heated gaseous

products is practically simultaneous throughout the mass. Such explosives are known as *detonating* or *high* explosives. That the presence of oxygen is not an essential to the formation of detonating explosives is demonstrated by the existence of certain detonating explosives such as the metallic azides, or metallic salts of hydronitric acid, *e. g.*, lead azide, PbN_6, which contain no oxygen. Explosives of this kind are usually in such unstable chemical equilibrium that a slight impulse serves to bring about the rearrangement of molecules and evolution of heated gas.

It should be noted that the physical state of an explosive has an important influence upon the character of the reaction, and may determine whether the explosive is to be assigned to one or the other of the classes above mentioned. Thus, certain cellulose nitrates in the form of guncotton can be detonated by the application of suitable shock, whereas cellulose nitrates capable of being formed into solid colloid solution are the principal components of the various modern smokeless powders, which are progressively burning explosives. The manner in which the decomposition of an explosive is initiated and the condition under which it progresses also influence the character of the reaction. Many of the detonating explosives can, by the application of flame, be burned in the open with a very moderate rate of combustion and are detonated in the same physical state only by the application of a very powerful shock. The slow burning of these substances can, however, hardly be called an explosive reaction.

Section II.—Initiation of Explosion.

3. The initiation of an explosive reaction is brought about by the application of energy in some form—usually by heat, impact, or friction. Many explosive substances can be exploded by the use of any one of the above-named forms of energy applied in the proper degree and manner. The amount of energy necessary to initiate explosion is a measure of the *sensitiveness* of the explosive to that particular form of application of energy. The total energy necessary may be quite different for the different forms of initiating impulse. For each explosive there is usually one preferred or common form of initiation. In technical and military usage heat and impact, in some form, are the most common.

4. Initiation by heat.—The burning explosives are commonly ignited by the application of heat, more particularly by flame. Most of the detonating explosives are capable of explosive decomposition by heat, especially if heat is applied suddenly in sufficient amount throughout the mass. They are also gradually decomposed by even moderate heat and this decomposition becomes accelerated by the heat liberated in the decomposition, and finally an explosion proper may result. This latter action, with most of the commonly used explosives, would require a very long period for its development.

5. Initiation by impact.—It is generally considered that in initiation by direct impact the action is due principally to the conversion of the energy of impact into heat, through pressure and friction. This method is found in common use in the various forms of percussion firing mechanisms in use in small arms and in larger ordnance, in torpedoes and in various forms of mines. In these devices it is only in the cap or primer, the first member of the explosive train, that the reaction is brought about directly by impact. An explosive substance sensitive to shock and friction as well as direct heat, usually some mixture containing fulminate of mercury, is used in a thin-walled cap which receives the impact of the firing pin. The flame and heat from the cap may be used to propagate further ignition through various courses to the main explosive charge or to initiate detonation through an intermediate chain, the first member of which is capable of detonation through heat alone.

6. Detonators.—Most detonating explosives, such as are used for the main charge in torpedoes, mines, and high-explosive shell, as well as in many forms of blasting, require for initiating their action a sudden application of very strong shock, such as is given by the detonation of another charge in contact with or in close proximity to them. This impulse is usually supplied by a sensitive detonating substance, such as fulminate of mercury and its mixtures, which can be detonated readily by the application of heat.

The devices used to initiate detonation in larger charges are called "*detonators.*" They consist usually of a charge of fulminate of mercury, or its equivalent, which is detonated by flame from a percussion cap, as described above, or, in electric deto-

nators, by flame from explosive substances ignited by contact with a bridge wire which is heated to incandescence by the firing current. In many forms of detonating charge there is an intermediate charge, or booster, between the detonator and the main charge. The booster charge contains more explosive than the detonator, but is small as compared with the main charge. As its name indicates, the booster charge is designed to multiply the impulse given by the detonator, providing a shock of sufficient intensity to propagate the reaction in all directions to the main charge. The explosive substance of the booster charge must obviously, either in constitution or in form, be more sensitive to the impulse of the detonator than is the substance of the main charge.

The initiation of explosion by "detonator" may be considered to partake of certain of the characteristics of initiation by heat and initiation by impact, since both heat and impact forces are provided by the detonator. That it is not limited by these elements alone may be shown by the fact that explosions can be initiated by influence without the direct application of heat or of impact, as generally understood.

7. **Initiation by influence.**—It has been frequently demonstrated that detonation in an explosive mass can be transmitted to other masses of detonating explosives in the near vicinity, without actual contact. It has been generally accepted that such transmission is due to the passage of an explosive percussion wave from one mass to the other. The influence of this explosive wave upon the second mass is such as to reproduce in it the detonating transformation. The second explosion occurring under these conditions is said to be initiated by *influence*. The secondary explosion or detonation is also frequently called a *sympathetic explosion* or detonation. The distance through which this action takes place varies with the kinds of explosive involved, the intervening medium and other conditions. Explosive waves will be discussed more fully in following paragraphs.

Section III.—Heat of Explosion.

8. An explosive reaction is always an exothermal reaction; that is, it is accompanied by a liberation of heat. The amount of heat or number of heat units set free may be found by applying known thermochemical laws. The applicability of these laws to explosive

reactions has been found and demonstrated by various investigators, particularly by Berthelot.

9. Heat of formation.—The application of these laws depends upon knowledge of the heats of formation of the initial substances and of the products of explosion.

The "heat of formation" of a chemical compound is the amount of heat given off or taken up when the compound is formed from its constituent elements.

Heats of formation have been determined for most chemical compounds, and are usually expressed in terms of large calories per *molugram*, the molugram of a substance being as many grams as there are units in the molecular weight of the substance (thus for H_2O the molecular weight is 18, and the molugram of H_2O is 18 grams). The *small caloric* is the quantity of heat required to raise the temperature of 1 gram of water (1 cubic centimeter) from 0° C. to 1° C. The *large caloric* is 1000 small calories. The simple elements such as oxygen and nitrogen, those names being found often in the products of explosives, have no heats of formation.

10. Calculation of heat of explosion.—The thermochemical principle on which the calculation of heats of explosives is based has been expressed as follows: *The heat liberated by a change of chemical condition in a system is equal to the excess of the heats of formation of the final products over the heat of formation of the initial substance.* This relation holds whether the final products are all gases or are gases and solids. It is also independent of the intermediate transformations which may take place before the final state of equilibrium is reached.

If we denote by Q the heat of the explosion, by Q_1 the heat of formation of the explosive substance, and by Q_2 the sum of the heats of formation of the final products of the explosion, the relation expressed above becomes

$$Q = Q_2 - Q_1.$$

If the heat of formation of the explosive substance is negative (that is, if it is an endothermic body, one whose formation is accompanied by absorption of heat) the above equation becomes

$$Q = Q_2 + Q_1.$$

In many explosives the final reaction products may differ somewhat, depending upon the conditions under which the explosion

takes place, and determination of the exact amount of heat liberated in any given explosion of such a substance will depend upon a knowledge of the exact constitution of the final products. The final products being known, the heat of explosion, referred to constant pressure and to a temperature of 15° C. for both the initial substance and the final products, may be calculated as in the following example:

The explosive decomposition of picric acid may be written as follows:

Molecular weights	..229	44	18	28	2	28
	$2C_6H_2(NO_2)_3OH =$	$CO_2 +$	$H_2O +$	$11CO +$	$2H_2 +$	$3N_2$
Heats of formation	..46.8	94.3	58.3	26.1	0	0

The sum of the heats of formation of the final products is $94.3+58.3+11 \times 26.1=429.7$. The heat of formation of the two molugrams of the initial substance which appear in the above reaction is $2 \times 46.8=93.6$

$$Q=Q_2-Q_1=429.7-93.6=336.1.$$

The heat liberated by the explosive decomposition of one molugram of picric acid is, since two molugrams are represented in the above calculation, 168.05 large calories.

Since the molugram of picric acid is 229 grams, the heat liberated by the explosive decomposition of 1 kilogram of picric acid is $\frac{168.05}{229} \times 1000=733.9$ large calories.

11. When the heat of explosion is referred to constant pressure, as in the above example, the explosive reaction taking place for instance in the open air, there is a heat loss equivalent to the work performed in expanding the gases and compressing the surrounding atmosphere. When the explosive and its decomposition products are confined to a constant volume throughout the reaction, the heat developed is increased by the addition of this heat equivalent. The relation between the heat developed at constant volume, Q_{tv}, and that developed at constant pressure, Q_{tp}, is as follows:

$$Q_{tv}=Q_{tp}+0.54(n_1-n)+0.002(n_1-n)t,$$

in which n and n_1 are, respectively, the number of units of volume shown in the chemical equation before the reaction and after the reaction, and t is the temperature of the surrounding atmosphere

In solid and liquid explosives the original volume is so small as compared with that of the gases evolved that n may be neglected, and we may write

$$Q_{tv} = Q_{tp} + 0.54n_1 + 0.002n_1t.$$

12. Measurement of heat of explosion.—Practical measurements of heats of explosion are carried out with very small amounts of explosive substances, fired electrically in a bomb calorimeter, which is similar in principle to the water calorimeter used in ordinary determinations of fuel values, but more strongly made. The water surrounding the bomb is constantly stirred after the explosion, and its rise in temperature is observed by means of a thermometer. The increase in temperature multiplied by the known water equivalent of the calorimeter gives the heat of explosion.

13. Heat energy of the reaction.—The heat of explosion represents the energy of the explosive system and hence its potentiality for work. This, however, does not give a real index of the capability or suitability of an explosive substance for a given purpose. The velocity at which the reaction takes place, the means necessary to initiate it, and a number of other characteristics to be discussed later, must be considered in selecting an explosive for a given purpose.

The energy content of explosives is much smaller than that of the commonly used fuel substances. For example, one kilogram of coal gives about 4000 calories, whereas the cellulose nitrate smokeless powders used in our guns give about 900 calories per kilogram. The velocity with which explosive substances liberate their heat is the chief characteristic which makes them valuable for the uses to which they are put.

Section IV.—Velocity of Explosion.

14. The velocity of explosive reaction may vary within rather wide limits, depending principally upon the kind of explosive substance under consideration and upon its physical state. Reference has already been made to the broad classes of burning explosives and detonating explosives and to the fact that certain explosive substances, such as cellulose nitrates, may, by changes of form and by additions, be used in either class. This behavior

of cellulose nitrates indicates the possible effect of *physical state* upon the velocity of reaction in an explosive.

The velocity of explosive reaction is much greater in the detonating or high explosives than in the burning explosives. The rate at which combustion proceeds in cellulose nitrate powders, for instance, in modern guns, is of the order of 12 cm. per second; whereas the velocity of detonation of high explosives ranges from about 2000 to 8000 meters per second.

It is generally considered that the velocity with which the initiating impulse is delivered may influence materially the velocity with which explosion is subsequently propagated, especially in high explosives, but this subject has not been investigated fully. For most practical purposes it may be considered that velocity of reaction in a given explosive substance in a given physical state is modified principally by its temperature and by the pressure under which the reaction takes place. Both of these elements, as they increase in value, accelerate the explosive reaction. The accelerating influence of increased pressures, especially in the burning explosives, is marked. Smokeless powders, containing nitrocellulose, or nitrocellulose with nitroglycerin, burn in the open or at atmospheric pressure at very moderate velocities; when burned in a confined space, as in a gun chamber, they are subjected to greatly increased temperature and pressure and their combustion is accelerated rapidly, the mean velocity of combustion under these conditions becoming roughly one hundred times greater. These increases in velocity of combustion are due principally to increased pressure. The smokeless powders, being homogeneous solids formed into grains of considerable thickness, burn in parallel or concentric layers, the combustion proceeding from one layer to the next throughout the mass. The increase of pressure as combustion proceeds brings the resultant heated gases in closer contact with each succeeding layer and the accelerated combustion results. Black powders are mixtures of materials not homogeneous; their grains are less uniform and more subject to crushing, and their structure is such as to give fine interstices within the grain for the passage of heated gases. Hence they do not burn as progressively from layer to layer as the smokeless powders do, and their rate of combustion is not so much influenced by increases of pressure.

15. Wave of detonation.—The velocity with which the explosive reaction occurs in detonating explosives has already been referred to. The transformation occurring in these explosives is propagated from point to point throughout the mass of the explosive by a progressive impulse due to the chemical reaction occurring. In this transformation there is a constant conversion of chemical energy into heat and mechanical energy, and the breaking down of chemical bonds is thus sustained throughout the mass of the explosive. This transformation is generally known as the "*wave of detonation.*" As previously stated, its velocity is very great, reaching more than 8000 meters per second in some explosives. The analogy between the detonation wave and other wave phenomena, such as sound waves, has been pointed out by some investigators. The detonation wave, like the sound wave, is transmitted at uniform velocity through a homogeneous medium and is subject to similar retardation in passing through restricted passages. It will be noted, however, that the velocity of the detonation wave is much greater than that of the sound wave in the same medium. There are other differences, some of which are complex and only imperfectly known. Expression by formulas of the relation between velocity of detonation and the other characteristics of various high explosives has been attempted with only partial success.

In a detonating reaction the force exerted expresses itself in two different forms. The first is the detonation wave already described, the effect of which is transmitted as a percussion blow, similar to the blow of a "water hammer," throughout the surrounding media. This has often been called a "static" blow. The second is the purely physical application of force due to the expansion of the gases resulting from the reaction. The action of this "wave" or force decreases in intensity with the square of the distance and it exercises its principal effect in the rending or crushing action of the rapidly expanding gases themselves or in the similar action of the surrounding material or medium actually propelled by their expansion.

The difference between the two effects discussed above is especially marked in underwater detonations. The percussive "hammer blow" due to the effect of the detonation wave is felt and recorded first in all directions from the detonation, sometimes

at considerable distances. The second manifests itself in the upheaval of masses of water propelled by the escaping gases. When the detonation occurs in contact with or near a vessel or other solid object, this second effect is added to that of the percussive wave in producing structural damage, and is the principal destructive factor. This applies particularly to surface vessels, or floating objects which are within the zone of the action. Submerged objects, such as submarines, even though not within the destructive range of the second effect here described, are subjected to an encircling pressure from the percussive wave and are therefore liable to damage from this cause. This crushing pressure may be sufficiently serious at moderate distances to sink or disable a submarine. It is this effect which makes a well-placed depth charge so effective against a submarine, even though the vessel may be outside the zone of the propulsive action of the expanding gases.

Section V.—Pressure of Explosion.

16. We have seen that the high pressure accompanying explosive reaction is due to the formation of gases which are expanded by the heat liberated in the reaction. The work which the reaction is capable of performing will depend, disregarding heat losses, upon the volume of the gases and amount of the heat liberated. The maximum pressure developed and the way in which the energy of explosion is applied will depend further upon the velocity of the reaction.

When the reaction proceeds at a comparatively low velocity the gases receive heat while being evolved at a moderate rate and the maximum pressure is attained comparatively late in the reaction.

If in the explosion of another substance the same volume of gas is produced and the same amount of heat is liberated, but the velocity of reaction is greater, the maximum pressure will be reached sooner and will be greater than in the preceding case. Disregarding heat losses, the work done will, however, be equal. Heat losses occur principally through the transmission of heat to the surrounding medium through conduction and radiation. When the time of the reaction is less because of its greater velocity these losses are reduced and the heat applied to the per-

formance of useful work through expansion of the gases is greater.

If the evolution of the gases could take place instantaneously, the maximum pressure would also be reached at once and the heat losses would be reduced to a minimum.

But for the heat losses, the expansion of the gases after the explosive reaction itself is complete could be considered a true adiabatic expansion.

17. The rapidity with which an explosive develops its maximum pressure is the principal factor of the explosive quality termed *brisance*. A "brisant explosive," generally so-called, is one in which the maximum pressure is attained so rapidly that the effect is to shatter material surrounding it or in contact with it.

18. In the following brief discussion of the properties and action of the gases resulting from explosive reactions, let

v_0 = the specific volume of the gas, that is, the volume of unit weight of the gas at a temperature of 0° C. and at normal atmospheric pressure.

p_0 = the normal atmospheric pressure, 103.33 kilograms per square centimeter.

v_{0t} = the volume of unit weight of the gas at $t°$ C. and normal atmospheric pressure.

p = any pressure to which the gas may be subjected.

v = the actual volume of unit weight of gas at pressure p and temperature $t°$ C.

α = the co-volume of the gas, which is the least volume into which unit weight of the gas can be compressed. In this volume the molecules of the gas are regarded as in actual contact with each other. (See Art. 20.)

W = the work done by the gases in expanding.

Δ = the density of loading, that is, the ratio of the weight of the explosive to the weight of a volume of water which would fill the chamber in which the explosive is contained.

c = the specific heat of the gas, that is, the quantity of heat required to raise the temperature of unit weight of the gas 1°.

T = the absolute temperature of the Centigrade scale.

19. Laws of perfect gases.—The following laws have been enunciated to express the properties of theoretically perfect gases. Actual gases do not follow these laws exactly, especially with changes of temperature and pressure.

Avogadro's law.—Equal volumes of gases at the same temperature and pressure contain the same number of molecules. Otherwise expressed, at the same temperature and pressure the densities of gases are proportional to their molecular weights. The molecular volumes of all gases, each being the volume of one molugram of the gas at 0° C. and at normal atmospheric pressure, are therefore equal.

Mariotte's law.—At constant temperature the pressure of a given weight of gas varies inversely as its volume, or, at t° C.,

$$pv = p_0 v_{0t} = \text{a constant.}$$

Gay-Lussac's law.—At constant pressure the coefficient of expansion of a gas for a rise in temperature of 1° is a constant, for all temperatures and pressures. The value of this constant for a rise in temperature of 1° C. is 1/273. From this law

$$v_{0t} - v_0 = \frac{t}{273} v_0,$$

or

$$v_{0t} = v_0 \left(1 + \frac{t}{273}\right).$$

From the above equations we may derive by combination the characteristic equation of perfect gases,

$$pv = p_0 v_0 \left(1 + \frac{t}{273}\right).$$

Since $\frac{p_0 v_0}{273}$ is a constant quantity for a given gas this is written

$$pv = R(273 + t).$$

$273 + t$ is the absolute temperature in the Centigrade scale, or T. Hence

$$pv = RT.$$

20. To express a similar relation for actual gases, in which the observed differences in their behavior from the theoretical behavior of perfect gases are taken into account, Clausius proposed the following form of a formula of Van der Waal:

$$p(v - \alpha) = RT - \frac{C(v - \alpha)}{T(v + \beta)^2}.$$

The correction α is known as the *co-volume* and may be roughly explained as follows: A "perfect" gas should be infinitely ex-

pansible or compressible. To be infinitely compressible its molecules must be compressible, but our conception of a gas is of a number of incompressible molecules not cohesive, but separated by varying distances dependent upon the rarefaction of the gas. The volumes of the molecules themselves are summarized into the fraction a of the total volume of the gas, and this fraction a is then termed the co-volume. The remaining volume or $V-a$ is considered the true volume of the gas for purposes of analysis, following the equation above.*

For gases at 0° C. and atmospheric pressure where V represents the volume of the gas, a is taken as .001. For smokeless powder, however, where V represents the solid volume of the powder, subsequently to be converted into gases, the amount of the gases, when liberated in the volume occupied by the solid powder, is so great that the correction a, in that volume, is approximately $\frac{2}{3}$. Different investigators assign values from .57 (as for black powder also) to 1.1 (a German authority). The mean value of $\frac{2}{3}$, or the reciprocal of the density of the powder, is employed in United States practice.

The constant β is based upon the cohesion of the gases. The constant C decreases very rapidly with increase of T, so that at the high temperatures attained in explosive reactions the second member of the equation approaches zero and may be disregarded. Hence, for explosive reactions, we may write the equation

$$p(v-a)=RT.$$

This equation, which agrees closely with the observed behavior of actual gases, may be called the characteristic equation of actual gases. It expresses the *maximum pressure* which the products of

* One molecule of fulminate of mercury undergoes explosive decomposition according to the equation,

$$Hg(CNO)_2 = 2CO + N_2 + Hg.$$

If these four molecules of gas should be compressed, their volume would decrease in proportion as the pressure increases, but only to a certain point where the molecules actually come in contact with each other. This volume, although it is *greater* than the volume of the molecule of mercury fulminate, cannot be further decreased. It represents the lower limiting volume of the new-formed molecules and is called the co-volume of the mercury fulminate.

explosion of the *unit weight* of an explosive exert upon unit surface in volume v.

For any weight $\bar{\omega}$ of gas occupying volume V, the maximum pressure $P=\dfrac{RT\bar{\omega}}{V-a\bar{\omega}}$.

By definition (Art. 18), $\Delta=\dfrac{\bar{\omega}}{V}$ or $V=\dfrac{\bar{\omega}}{\Delta}$, which value of V, substituted in the equation, gives the relation between maximum pressure and density of loading, Δ, as expressed by the equation

$$P=\frac{RT\cdot\Delta}{1-a\Delta}.$$

21. Expansion of gases.—Mention has already been made of the fact that the heat imparted to the resultant gases of the explosive reaction furnishes the energy which the expansion of the gases converts into work. As the gases expand they give up their heat, just as steam does in expanding in an engine, and their temperature falls. The work done, whether it is expressed in propelling or disruptive force, or given up in heat to surrounding media, depends upon the number of heat units liberated by the explosive into its gases. The work which can be performed by one large calorie, the unit used in the preceding discussion of the heat of explosion, is 425 kilogram meters. This is the mechanical or work equivalent of heat, usually denoted by E. In determining the work of which an expanding gas is capable, the specific heat of the gas must be known. The specific heat of a given gas may vary with the temperature and is ordinarily determined under (a) constant pressure, (b) constant volume. If c_p is the specific heat of the gas at constant pressure, and c_v its specific heat at constant volume, the work of which unit weight of the gas is capable for a change of 1° in temperature is $W=(c_p-c_v)E$.

Since the conditions for adiabatic expansion require that no heat be added to or given up by the gas in expansion, the expansion of the gases of explosion can be considered to follow adiabatic laws only in part. In a burning explosive heat is being added practically throughout the useful expansion because of the comparatively moderate progress of the reaction. Furthermore, under these conditions a considerable quantity of heat is given off during the expansion in heating surrounding materials, such as the gun barrel, for instance, in the case of propellent powders. The gases

from detonating reactions follow more closely the adiabatic laws, since the entire volume of gas is evolved almost instantaneously and, under usual conditions, the expansion and performance of work proceeds with great rapidity with a minimum loss of heat.

Section VI.—Temperature of Explosion.

22. If all of the heat liberated in an explosive reaction were applied to the heating of the products of explosion, the rise of temperature in these would be

$$t = \frac{Q_{mv}}{c_{mv}},$$

Q_{mv} being the heat of explosion for constant volume, and c_{mv} the mean specific heat of the products of explosion.

Experimental determination of the specific heats of gases and other substances at the extremely high temperatures involved in explosive reactions is difficult. Various investigators have endeavored to find the true or relative values involved. It is usually assumed that the specific heat varies with the temperature in accordance with the equation

$$c_{mv} = a + bt,$$

in which a and b are constants determined experimentally.

Substituting this value in the foregoing equation, we get

$$Q_{mv} = at + bt^2$$

and

$$t = \frac{-a + \sqrt{a^2 + 4b \cdot Q_{mv}}}{2b}.$$

Mallard and Le Chatelier in their comprehensive investigations of this subject deduced the following values of a and b for certain of the commonly occurring gaseous products of explosion, c_{mv} being expressed in small calories:

CO_2; SO_2 .... $a = 6.26$, $b = 0.0037$
H_2O (vapor) .... $a = 5.61$, $b = 0.0033$
N_2, H_2, O_2, CO...... $a = 2.80$, $b = 0.0006$

If, as in the earlier discussion of heat of explosion, Q_{mv} is expressed in large calories, its value in the last equation must be multiplied by 1000 in using the values given for a and b and hence for c_{mv}. If the products of explosion are partly solid the quantity

of heat absorbed in raising their temperature must be taken into account. By way of example, and to illustrate the extremely high temperatures attained, it may be mentioned that the calculation of the explosive temperature of nitroglycerine by the above method has resulted in 3470° C.

23. The value of the maximum temperature of explosion is of practical technical importance in certain applications of explosives. In gaseous coal mines, for instance, the temperature at which the gases present are capable of being ignited would influence the choice of the blasting explosives used in the mines. Generally, however, the permissible explosives are determined by direct experimental means. In guns the temperature of explosion or combustion attained influences the accuracy-life of the guns by its effect upon the *erosion*.

Since the practical measurement of explosion temperatures is nearly impossible with present means, their theoretical calculation is of value, especially as the actual temperatures attained may be assumed to be less than the calculated maxima.

Section VII.—Gases of Explosion.

24. In the foregoing discussion of explosive phenomena it has been implied that the products resulting from explosive reactions are capable of quantitative determination, and that the chemical changes occurring throughout the reactions are known. Practically such information can usually be gained only approximately. The usual method involves the explosion of small quantities of the explosive substance in a strong container or bomb from which the air has been evacuated. When the pressure within the bomb has attained a standard condition by cooling, the gaseous products are drawn off for examination and the solid products removed by washing out. During the interval between explosion and examination, the conditions surrounding the products of explosion have thus undergone changes which may have resulted in alteration in their constitution. Their composition at the moment of explosion must therefore be estimated by theoretical considerations, aided by knowledge of the compositions of the initial substance and of the products as finally examined. The explosive reaction is complex in many cases, and the physical and chemical transformations through which the resultant products pass under various con-

ditions as the reaction progresses are but imperfectly known. The final products themselves are capable, in some explosives, of a considerable variation depending upon the conditions surrounding the reaction, especially when, in oxygen-carrying explosives, there is not sufficient oxygen for complete combustion.

The principal gaseous products of the explosives more commonly used are carbon dioxide, carbon monoxide, water, nitrogen and nitrogen oxides, hydrogen, methane and hydrogen cyanide. Some of these gases are suffocating, others actively poisonous. The gases from propellent explosives are rarely dangerous since they usually escape at once into the open and are dissipated and diluted with air. Generally speaking, the commonly used high explosives not only produce a larger proportion of noxious gases, but their normal conditions of use tend toward a lingering presence of the fumes. Thus in mine and quarry operations the gases are imprisoned more or less and are given off slowly from the shattered material; whereas in military use shells filled with high explosives burst usually after penetration into confined spaces, whence the gases are not quickly evacuated; and the same conditions may apply to a vessel holed by a torpedo or mine.

25. Flame of explosion.—Explosion is nearly always accompanied by flame due to the high temperature at which the reaction takes place. Some of the gaseous products of explosion are themselves inflammable or form explosive compounds with air. Among these are hydrogen, carbon monoxide, and methane, all of which occur in the gaseous explosion products of smokeless powders. The large volume of flame occurring at the muzzles of guns upon discharge is considered largely due to the rapid inflammation or explosion of these gases mixed with air. This secondary reaction is not necessarily complete and portions of the explosive mixture remaining in the bore of the gun, or blown back by adverse winds, have been known to be ignited by glowing or burning residue in the bore. If the breech of the gun is open the resulting explosion may transmit flame to the rear of the gun. This action has commonly been called *flareback*. Serious accidents due to the ignition from this cause of fresh charges of powder being served to the gun have led to the adoption of the various gas-expelling devices fitted to guns fired from closed compartments, more particularly on naval vessels.

26. Flashless charges.—The advantages to be gained by reducing or suppressing the flash of guns in military operations—disguising of the location of guns firing at night and avoidance of the effect of blinding glare upon operating personnel—have led to partially successful efforts to produce flashless charges. A number of various additions to the charge have been used in different services for the purpose. They have usually been substances which would tend to lower the explosion temperature or would be dispersed throughout the gases in a fine dust. A usual result of suppression of flash by such means is an increase in the volume of smoke. The desired reduction of flash is secured more easily in low-powered than in high-powered guns. A number of theories have been put forward to account for the extinction of flash by these means, none of which are general in their application or have found general acceptance.

CHAPTER II.

SERVICE EXPLOSIVES.

Section I.—Brief History of the Development of Explosives.

27. The chemical constitution and physical form of modern explosives and the methods employed in handling and making use of them have resulted from a gradual development such as has been characteristic of the progress of so many other of the useful arts. A brief review of the more important phases of the history of the explosives art will be given as an aid to clearer understanding of the considerations which have governed the choice of the forms of explosive substances now used and their adaptation to present-day purposes.

28. **Early incendiary substances.**—Fire has, of course, been used as a weapon of war since the earliest recorded time and the transition from the use of ordinary combustibles to materials and mixtures of greater incendiary efficiency was a natural consequence of the gradual advance in physical and chemical knowledge. In the defense of Constantinople against the Moslems in the 7th and immediately succeeding centuries, the Greeks made very effective use of the so-called "Greek fire," particularly in naval engagements. This material was projected in flaming streams from tubes carried in the bows of the Greek vessels. It seems to have consisted of petroleum oils with the addition, perhaps, of sulphur. Similar materials were used both in streams of flame and in missiles by the Moslems during the Crusades, and knowledge of their use thus spread to other countries. Incendiary mixtures of this type were known during the Middle Ages as "sea fire" and "wild fire." The early incendiary weapons were the forerunners of the modern flame thrower.

29. **Black powder.**—When the properties of saltpetre, or potassium nitrate, became widely known, in about the 13th century, this substance was added to the earlier mixtures and a close approach was made to gunpowder. Charcoal soon came into use as the carbon-carrying constituent and the evolution of gunpowder

was then complete. The use of saltpetre in incendiary mixtures seems to have been introduced by the Arabs and the Chinese at about the same time during the period referred to above. Knowledge of these mixtures, their uses and methods for their manufacture spread rapidly, especially after the first firearms were made, early in the 14th century.

The gunpowder of these early times was, in its proportions as well as in its ingredients, much like the black powder in use to-day. Its history, through the centuries in which it remained the only widely known and used explosive, records development through changes of form and of methods of manufacture, rather than of chemical constitution. It was at first a very fine mealy powder. Later it was formed into rough grains, separated and graded into various sizes by sifting. Still later, compactness of the grains was secured by forming the powder into cakes under a considerable pressure before breaking it up into grains.

For a long time gunpowder was used only as a propellant in small arms and in cannon. It then was turned to account in blowing up enemy fortifications and later for more peaceable forms of blasting. After powder-train fuses had been successfully made, it came into use as a bursting charge for projectiles.

In the early firearms, including cannon, the powder charge was ignited by the application of an open flame to a priming hole. The flintlock of the 18th century gave the first important improvement in methods of ignition. In this device the priming charge was ignited by sparks struck by the impact between flint and steel. Improved firing locks and the introduction of mercury fulminate came early in the 19th century and modern means of ignition have followed directly from them. Fulminate mixtures, in caps struck by a firing pin, or in containers where they are ignited by the heating of electric bridges, are still the most widely used means of initiating the action which results in the burning of the charge of propellent explosive in a gun, or the detonating of a high-explosive charge in a projectile, a torpedo, or a mine.

Although the compression and granulation of black powder had given a partial improvement in its performance in guns, it remained difficult to regulate the action, especially in larger ordnance. In attempting to increase muzzle velocities to get greater range and penetrating power, it was found that the gun

chamber pressures soon became excessive because the powder burned too quickly. In 1860 General Rodman, of the United States Army, realizing the advantages to be gained by increasing the time of burning of the charge, proposed the use of large grains of very dense powder for this purpose. As a result of his researches he also proposed that perforated grains be used in order that the burning surface of each grain might be increased as combustion proceeded. The use of grains such as developed by General Rodman gave means of regulating much better the ballistic action of black powders and such grains therefore came into general use. Various forms were common, such as the spherohexagonal and various prismatic shapes, including the hexagonal prism with a single perforation. The latter form was widely used in large guns. The use of such grains was the first notable advance in securing a powder which would burn *progressively,* that is, with increasing evolution of gases and heat.

The last form of charcoal powder to be used in cannon was the "brown" or "cocoa" powder introduced about 1880. An underburned straw charcoal was used in this powder and gave it the characteristic color from which it took its name. This charcoal gave a denser and hence slower burning structure to the powder and permitted better regulation of pressure.

30. Cellulose nitrates and smokeless powders.—In 1838 Pelouze discovered that an explosive could be produced by nitrating cotton, that is, by treating cotton with nitric acid in such a way as to cause NO_2 groups from the nitric acid, HNO_3, to enter into combination with the cellulose of which the cotton is so largely composed. He thus produced cellulose nitrates, generally called nitrocellulose. His explosive was the first guncotton, but it was a very imperfect product and was not put to practical use. In 1845-46 Schonbein discovered that by nitrating cotton with a mixture of nitric and sulphuric acids an explosive of good quality resulted and that the nitration process could be controlled with some readiness. His process soon gained rather wide application since its importance in explosives manufacture was readily perceived.

Manufacture of guncotton was undertaken in several European countries, but received severe setbacks through the occurrence of disastrous explosions in several factories in which it was being

made. The researches of various investigators, notably of Von Lenk in Austria and Abel in England, showed that the danger which had hitherto attended the manufacture of guncotton was due to the presence of impurities which could be removed by careful courses of treatment. The methods of purification which they introduced consisted principally in washing and boiling, together with pulping the material to facilitate cleansing. (See Art. 42(e)).

The earlier attempts to use guncotton as a propelling charge in guns were not successful. The velocity of the reaction was too great to permit of controlling the pressures, which were such as to burst many guns in which the explosive was used. Various measures were taken to retard the combustion, and cellulose nitrate powders, which were partially suitable for use in small arms, were produced by various makers. The solubility of cellulose nitrates in a mixture of ether and alcohol was noted by several who investigated its properties. The first to make successful application of this property of the material in producing a satisfactory propellent explosive was the French chemist Vieille, to whom was due a large part of the advance in knowledge of explosives. By thorough mixing of the nitrated cotton and the solvent he produced a gelatinous mass or *colloid,* which became quite hard and dense when the solvent was evaporated out. The resulting substance burned progressively and at moderate rates. The colloid was capable of being worked into the desired shape before drying and its formation into grains or strips to secure control of its burning was made possible. Vieille's first powder of this kind, called Poudre B, was made in 1884. The improvements which have been made in smokeless powders since that time have been principally in the direction of better methods of purification and other measures for insuring chemical stability, although the technique of each of the other steps in the manufacturing process has also progressed in efficiency.

31. High explosives.—Nitroglycerine was discovered by Sobrero in 1846, but its highly explosive properties were not turned to account until Nobel, about 1860, found that it could be detonated by means of a small charge of fulminate of mercury. Nobel found also that nitroglycerine could be used effectively and with much greater safety when mixed with various absorbent

materials. He began the manufacture of such mixtures, which have developed into many forms and have become widely known and used under the general name of dynamites.

The nitration of cellulose and of glycerine to form powerful explosive substances led quickly to the discovery of a number of other explosives produced by the nitration of hydrocarbons, particularly of the aromatic hydrocarbons found in coal tars. One of the earliest additions to the list was picric acid, which had been known as a dyestuff long before its explosive properties were discovered and employed. Others have followed in great number and variety.

Mixtures of various high explosive compounds with other substances, usually oxygen carriers, have also been developed and used, mostly for commercial purposes. The variety of widely known and used explosive substances has now become so large that the military explosives to be discussed in the remainder of this chapter comprise only a limited portion of the explosives field.

Section II.—Explosive Substances: General Characteristics.

32. In the preceding chapter we have defined explosive substances and discussed the general characteristics of the reactions to which they give rise. In this section we will consider the characteristics of the explosive substances themselves and of the materials from which they are made.

33. Explosive mixtures and explosive compounds.—Regarded from the point of view of their composition, explosives may be divided into two classes: (1) *explosive mixtures,* (2) *explosive compounds.*

Explosive mixtures consist of an intimate mixture of distinct substances, properly prepared and conglomerated mechanically in varying proportions. Such explosive mixtures must have at least some oxygen supplier, such as a nitrate or chlorate, and some combustible, such as carbon or sulphur. Black and brown powders are typical examples of such mechanical mixtures.

Explosive compounds consist of substances whose molecules contain within themselves the oxygen, carbon, and hydrogen necessary for combustion. They are true chemical compounds and are therefore homogeneous in constitution. They have weak

molecular bonds, due to the presence in their molecules of weak bonding radicals, such as NO_2. They are therefore in a state of unstable chemical equilibrium.

Mechanical mixtures can be graded by varying the proportions of the ingredients. The elements constituting an explosive compound are always present in the molecule in the same quantities, according to the law of fixed proportions; therefore the nature of the explosive cannot be graded by varying the quantities of the constituent elements as in the case of mechanical mixtures. It is to be noted, however, that the same initial substance may, in many cases, yield different explosive compounds by nitrating to different degrees. The different products are, however, generally distinct chemical compounds.

The explosive compounds consist very largely of nitrated hydrocarbons. The nitration results in the introduction of NO_2 groups into the molecules of the hydrocarbon. The nitration is almost always effected by treating with nitric acid mixed with sulphuric acid. Most of the explosive compounds which are nitrated hydrocarbons are derived from hydrocarbons of the aromatic series. Most important of these basic hydrocarbons are benzene, toluene, xylene, naphthalene, anthracene, and their derivatives, all of which are found in the coal tars resulting from the distillation of coal to produce coke. Among the principal explosives derived from the aromatic hydrocarbons are trinitrotoluene and picric acid, together with the picrates. Of the explosive compounds derived by nitration of non-aromatic hydrocarbons, the most important are the cellulose nitrates and nitroglycerine.

34. Uses of military explosives.—Viewed from the standpoint of the military uses to which they are put, explosives may be divided into three classes:

(1) *Burning, progressive, or propellent explosives* (*low explosives*). In this class are included all powders used to propel projectiles from guns.

(2) *Detonating or disruptive explosives* (*high explosives*). This class includes the explosives used for bursting projectiles and for the main charge in torpedoes, mines, aero-bombs, and for most demolition purposes.

(3) *Detonators or exploders.* These are high explosives used in small quantity to initiate explosive reactions in charges of explosives belonging to the two classes above.

35. Propellants.—Smokeless powders of one form or another are now used almost universally for propellent charges. For military purposes, especially for guns larger than small arms, they may be considered to be of two classes, (a) *single base powders* and (b) *double base powders.* In the "single base powders," cellulose nitrates, which will hereafter be referred to as nitrocellulose, form the only explosive ingredient. The other materials present in single base powders are present to give suitable form and stability to the powder. In the "double base powders," nitroglycerine is present to assist in dissolving the nitrocellulose during manufacture, as well as to add to the explosive qualities of the powder.

The single base nitrocellulose powders contain proportionately less oxygen than the double base powders. The resultant gases from the single base powders contain therefore relatively less of carbon dioxide, CO_2, and relatively more of carbon monoxide, CO, than do the double base powders. The heat liberated by equal weights of the two powders is therefore greater in the case of the double base powders, since the heat of formation of CO_2 is greater than the heat of formation of CO. The conversion of carbon to carbon monoxide produces a greater volume of gas than its conversion to carbon dioxide. The single base powder therefore produces a greater volume of gas, though less heat than the double base powder. From a thermodynamic standpoint, it is therefore somewhat less efficient, but it has the advantage of causing less *erosion* in the gun because the resulting temperatures are lower. (See Art. 180.)

Single base powders are used in France and in the United States. Double base powders containing nitrocellulose and nitroglycerine are used in England, as "Cordite," in Italy, in Spain, and various other countries.

36. Igniters.—Charcoal powders are now no longer used as propellants in military rifles. In the form of black powder, they are now used to facilitate ignition of smokeless powder charges, since they themselves are more readily ignited; in fuses, to propagate flame from one part to another; for saluting charges; for bursting charges in certain classes of projectiles; and for various other purposes.

37. Detonating charges.—Large charges of high explosives are used as the main charges of torpedoes, mines, aero-bombs, and various classes of projectiles. The explosive most commonly used for these purposes during recent years has been trinitrotoluene, generally known as TNT. This material has also been called trinitrotoluol, trotyl, trinol, trilite, tritolo, and by various other names. For a number of years prior to the World War, guncotton was the preferred explosive material for torpedoes and mines, whereas picric acid or its derivatives were used commonly for the bursting charge of projectiles. TNT has practically supplanted guncotton because of its greater safety, stability, and convenience. It has also replaced picric acid and the picrates for filling certain classes of projectiles, especially those not intended for piercing armor plate.

TNT was used in such quantities during the war that shortages in the materials required for its manufacture were threatened. This led to efforts to find satisfactory materials which could be mixed with TNT in order to conserve the available supply and yet secure powerful explosive mixtures. These efforts led to the adoption in various services of such explosives as amatol and sodatol, which consist of mixtures of TNT with ammonium nitrate and sodium nitrate, respectively.

The material adopted by the United States Navy for mixing with TNT was trinitroxylol, or TNX, which is closely related to TNT. Xylene and toluene, the substances from which these explosives are obtained by nitration, are, as previously mentioned, both derived from coal tar.

Picric acid and the picrates are still largely used as bursting charges for projectiles since they possess advantages over TNT for certain classes of projectiles. They are preferred for armor-piercing projectiles because of the fact that they do not deflagrate or give incomplete explosions in passing through armor plate as readily as does TNT. Since an armor-piercing projectile will be more effective when bursting inside an armored structure after penetration than when bursting in passing through the armor, the characteristic discussed above becomes of much importance in selecting bursting charges. Picric acid and its derivatives have been used in various countries under the name of lyddite (English), melinite (French), explosive D (United States),

shimose (Japanese), and ecrasite (Austrian). TNT has been used extensively as the bursting charge in high-explosive projectiles not intended to be fired against armor.

The general requirements of high explosives for projectiles, applying particularly to armor-piercing projectiles, are given below:

(1) Should be reasonably safe to manufacture, and free from injurious effects to the operators as far as possible.

(2) Must show a safe degree of insensitiveness in ordinary handling.

(3) Must withstand the maximum shock of discharge from the gun under repeated firings in the projectile for which it is intended.

(4) Must withstand the shock of impact without explosion when fired in fused projectiles against the strongest plate that the projectile alone will perforate without breaking up.

(5) Must be uniformly and completely detonated with the service detonating fuse.

(6) Should possess the greatest explosive power compatible with other necessary requirements.

(7) Must not decompose when a dry or wet sample is hermetically sealed and subjected to a temperature of 65.5° C. for one week.

(8) Should be non-hygroscopic, and must not have its facility for detonating affected by moisture that can be absorbed under ordinary atmospheric conditions of storage and handling.

High-explosive charges are usually loaded by melting and pouring if the kind of explosive substance used permits of this treatment. This gives greater density to the charge and hence greater explosive effect in a container of given volume. TNT lends itself especially to the casting of charges.

38. Detonators.—A discussion of the function of detonators, including boosters, was given in the preceding chapter. Detonators are of a great variety, in both mechanical and explosive details. The detonating materials used in detonators and boosters are chosen for their efficiency in detonating the explosive substances of which the main charge is composed. The detonating reaction itself begins with a small charge of fulminate or fulminate mixture and is transmitted through the booster to the main

charge. The substances now most commonly used for the detonating trains and for boosters are tetryl, picric acid, and crystalline TNT.

Section III.—Manufacture and Characteristics of Service Explosives.

39. In this section will be given brief notes on the manufacture of certain explosives now used in the United States Navy, with further reference to the properties and characteristics of each. Inasmuch as the details of manufacturing methods and equipment change somewhat from time to time and vary to some extent between different manufacturers, such details will in general not be given fully. Attention will be directed more closely to the principles followed in manufacture and the precautions taken to insure safety in manufacture and purity and stability of the product.

(1) SMOKELESS POWDER.

40. The smokeless powder used by the United States Navy is a uniform ether-alcohol colloid of carefully purified nitrocellulose. A small quantity of diphenylamine is added in the course of manufacture to assist in preserving the chemical stability of the powder. The powder is made to conform to very rigid manufacturing specifications, which insure a very pure product, and to rigid ballistic specifications, which insure uniformity of performance in the gun. Except for minor differences in specifications, the same kind of powder is used by the United States Army.

41. Raw materials.—The principal raw materials used in the manufacture of United States Navy smokeless powder are the following:

(a) **Cotton.**—The cellulose material to be nitrated consists of bleached and purified unspun cotton wastes or short-fibered cotton, the latter being obtained through the removal of the fiber ends which are found adhering to the cotton seed after the ginning process. Short-fibered cotton is particularly suitable for nitration because the nitrating acids can reach all parts of it readily, which tends to uniformity in nitration.

The purification to which the cotton has been subjected before it is received at the powder factory consists usually in boiling with

caustic soda to remove impurities, especially the waxy constituents of the fiber, and to make those which remain more readily removable in the purifying processes undertaken later during the course of manufacture. The cotton is then bleached with chlorine, washed, and dried.

(b) **Acids.**—A mixture of nitric and sulphuric acids is used in the nitrating process. Mixed acids as made or received at the factory are required to conform to rigid specifications as to purity and strength. The mixture as received has a total acid content of about 95 per cent and the proportion of nitric and sulphuric acids is about equal. The acid as used directly in the nitrations is mixed with weaker acids which have been used in previous nitrations, in which they have lost a part of their acidity. These weaker recovered acids are known as *spent acids* and the process of mixing them with the fresh acid mixture is known as *fortifying* the *spent acids*. The usual acidity of the nitrating mixture is about 85 per cent, but this is varied somewhat with changing conditions, especially with changes in temperature. The proportion of the acid constituents is about two parts of nitric acid to one of sulphuric acid, by weight.

(c) **Ether and Alcohol.**—A mixture of ethyl ether and ethyl alcohol is used as a solvent for the nitrocellulose, as will be described later. They are required to be of a high purity.

(d) **Carbonate of soda.**—Carbonate of soda is used in the water in which the nitrocellulose is boiled during certain stages of the purification process. It also is required to be of a high degree of purity.

(e) **Diphenylamine.**—Diphenylamine, a pale yellow crystalline organic substance with a slightly alkaline reaction, is incorporated with the powder in order to neutralize any acid products which might be formed in the powder as a result of gradual decomposition. Diphenylamine thus arrests decomposition and hence adds to the chemical stability of the powder. It is therefore called a "*stabilizer.*" Other substances with similar chemical characteristics and reaction are available as stabilizers and have been used in various countries.

42. Steps in manufacture.—The following description of the processes by which United States Navy smokeless powder manufacture is carried out represents general or typical processes. As

previously pointed out, the details of the equipment and procedure differ slightly with various manufacturers. The principles followed and the principal steps necessary are, however, the same for all.

(a) **Picking of cotton.**—The purified cotton as received at the powder factory is picked by machine to loosen it and to permit removal of possible small bits of foreign matter which may have escaped previous inspections. Long-fibered cotton and short-fibered cotton are treated differently in the picking process, the former being combed or carded in a mill having toothed rolls, the latter being ground between corrugated plates. The picked cotton, in both cases, passes from the picker to a bin from where it is taken to the dry-house in canvas bags.

(b) **Drying.**—The cotton is dried to a moisture content of less than 1 per cent before nitration. Moisture in the cotton during the nitration process would tend to non-uniformity of nitration and increase the danger of burning the material due to the heat evolved by the interaction of the acids and the moisture. The cotton is dried by passing on a belt conveyor through an enclosed drying chamber through which air heated to 100° C. is circulated. In another drying system sometimes used, the cotton is dried in large bins with wire mesh bottoms, lined with burlap. Air heated at about 100° C. is passed through the cotton, being driven through ducts to the bins by a fan blower. The usual time of drying by these systems is about 12 hours.

(c) **Mixing acids.**—The acid mixture used in nitration is obtained by fortifying spent acids as already described. The amount of fresh acid mixture to be added is calculated from chemical analysis of samples taken from each tank of spent acid. The fortified mixture is brought to a temperature of about 30° C. in heating tanks before delivery to the nitrators.

(d) **Nitrating.**—The first stage of the nitration consists in the immersion of a charge of dried cotton in the heated mixed acids. The various nitrating processes differ principally in the nature of the equipment used for this immersion and the subsequent disposal of the spent acids and nitrated cellulose resulting. In one process generally used, about 1500 pounds of the fortified acid mixture is run into an iron pot in which means for stirring the charge are provided, generally by power-driven paddles. About

30 pounds of cotton is immersed in the pot and the mixture of acids and cotton is stirred during the time the acids are acting upon the cotton. Means are provided for carrying off the fumes resulting from the reaction. About 20 minutes suffices for the reaction, at the end of which time the cotton has been nitrated to the required degree, when it contains 12.60 ± 0.10 per cent of nitrogen. At the end of this stage the cotton and acids are run off into a centrifugal wringer, which is a perforated iron basket upon a central shaft with means for rotating at high speed. The basket is surrounded by an iron casing in which are provided drain outlets for the running off of the spent acids which are removed from the charge by centrifugal force due to the rotation. The inner basket permits the acids to pass through but retains the nitrated cotton. After the wringing is complete the nitrated cotton, which will hereafter be called pyrocellulose or pyro, is drawn off into a basin where it is immediately immersed in fresh water.

In certain cases, the nitration and wringing are both carried out in the centrifugal wringer. In another process, known as the displacement process, the nitration is carried out in a pan, in which the mixture of cotton and acids stands quietly until the nitrating reaction is complete. At the end of this time the spent acids are carried off by running cold, fresh water into the charge and allowing the spent acids to run off simultaneously as they are displaced by the water, the volume of material in the nitrating pot being kept constant.

The chemical processes taking place during the nitrating reaction are not entirely clearly defined. It has been generally accepted that the first action is a conversion of the cotton into cellulose sulphates by the action of the sulphuric acid, with the liberation of water. The nitric acid acts upon the cellulose sulphates so formed, displacing the sulphuric acid constituents and producing cellulose nitrates. The sulphuric acid liberated in this reaction combines with the water resulting from the previous reaction to form hydrates. The replacement of cellulose sulphates by cellulose nitrates is not complete and a certain portion of the sulphates remain as impurities, to be removed in the subsequent purification processes.

(e) **Purifying.**—The first step in the purification process takes place in the immersion basin previously mentioned.

(1) **Drowning.**—In transferring the pyro from the wringers the transfer is carried out as quickly as possible and the pyro is immediately immersed, or drowned, in water. If the pyro should be exposed to the air for any considerable period, it is likely to take fire through the action of the nitrating acids not completely removed in the wringing process, and to burn slowly with an evolution of dense nitric fumes. In the displacement process referred to above such burning cannot occur, as the pyro is completely immersed during the time the acids are being replaced with water. When the wringer process is used the pyro, after being transferred to the immersion basin, is run thence by pumps or by gravity to boiling tubs where the next step in purification is carried out. During this transfer the pyro is still completely immersed and most of the free acids remaining in the pyro as it comes from the wringer pass off into the water.

(2) **Preliminary boiling.**—The boiling tubs are large wooden tanks fitted with feed pipes and drain pipes for the admission and draining off of water, and with perforated wooden false bottoms. The perforations in the inner botton of the tub permit the passage of water, but hold the pyro. Into the space betwen the false bottom and the bottom of the tub is led a steam supply pipe which is perforated for the admission of steam into the water contained in the enclosed space. The pyro is protected from direct contact with the steam pipe, which is encased in a wooden trunk, except for the portion which lies under the perforated false bottom. The tub is nearly filled with fresh water, in which the pyro is immersed, and the steam is turned on. The temperature is gradually raised to 80° C. for a short time, when the steam is turned off and the water drained from the tub. A fresh supply of water is run in, heated to 100° C. by the steam, and the boiling is continued for about four hours. This boiling is repeated several times, the water being changed in each instance.

(3) **Pulping.**—After the preliminary boiling the pyro passes to pulpers, where it is finely ground to permit the next step in purification to reach all parts of the fiber, and to reduce it to a consistency which is desired in the later operations.

The pulper usually used is nearly the same as is used in many paper mills for the pulping of rags. It is a long tank, with a cast-iron roller carried in a horizontal position near the middle of the

pulper. Above and below the roller are concave plates which fit the roller, with very small clearances, throughout its length and over an arc of about 20° at top and bottom. The roller and the plates have sharp longitudinal ribs or knives which cut and grind the pyro passing between them. The pulper is kept nearly full of water and is fitted with baffle plates to direct the circulation of the water and pyro in such a way that they pass first under and then over the rotating roller. A bailer is provided to permit of changing the water during the pulping operation. The bailer consists of a hexagonal frame, the sides of which are covered with a fine screen, which permits water to pass through into the inside of the bailer and thence to an exhaust pipe, but does not allow the pyro to pass through.

The pulping operation is usually completed in about eight hours. The water and pyro from the pulpers are run through a pipe line to the poachers, in which the final step in purification takes place. Before passing into the poachers the water and pyro pass through a very fine screen or filter which rejects the particles of pyro which are still too coarse. This part of the pyro is returned to the pulpers.

(4) **Poaching.**—The poachers are large cylindrical wooden tubs similar to the boiling tubs. They are fitted with intakes and outlets for pyro and water, water supply pipes, and perforated steam pipes protected by a baffle. There is also a set of paddles carried by a rotating vertical shaft in the center. In the poachers the pyro is boiled, by the action of steam admitted through the steam pipe, and is stirred constantly by the paddles. In the first boiling carbonate of soda is usually added to the water to assist in purification. The operation continues about six hours, when the pyro is allowed to settle for one hour, the water is replaced by fresh water and the boiling is repeated for two hours, and then for four one-hour periods, the water being changed after each boiling as described above. The water is changed again after the last one-hour period of the boiling and the pyro is washed by stirring without heat for half an hour. It is allowed to settle for one hour, when the water is changed and the washing repeated. Ten such washings are given. No carbonate of soda is used after the first boiling.

After this course of purification is completed a sample of the pyro is taken from the poacher and given the prescribed chemical

tests for stability. If it is sufficiently pure to pass these tests, it is run out of the poacher to a centrifugal wringer where much of the water is removed from it. If it does not pass the chemical test, it is given further treatment in the poachers to increase its purity.

(f) **Dehydrating.**—From the wringers the pyro, containing still about 40 per cent of water, passes to the dehydrating house. Here the remaining water is forced out of it by forcing alcohol into it under pressure. A charge of about 50 pounds of pyro is loaded into the cylinder of a hydraulic press, where it is subjected to a pressure of about 200 pounds per square inch. This compression takes place between two pistons entering the cylinder from opposite directions. The upper piston is raised and alcohol is run in on top of the pyro cake. Air under about 75-pounds pressure is admitted over the alcohol, which is forced through the cake, leaching the water out of it. The cake is then given a final pressing between the pistons, to remove the excess alcohol. The amount of alcohol then remaining is approximately that desired in the ether-alcohol solvent.

(g) **Mixing.**—The compressed cake of pyro from the dehydrating press is taken to the mixing house in a metal can. Here it is broken up in a mixer, which is a water-jacketed iron container, with electrically driven rotating screw paddles inside. It is practically the same as the dough mixers used in bakeries. The pyro containing alcohol is mixed for about 20 minutes in order to break it up thoroughly. The ether constituent of the solvent is then added, in about twice the amount of the alcohol constituent already present. The stabilizing substance, diphenylamine, is also added at this stage, being dissolved in the ether before the ether is poured into the mixer. The weight of diphenylamine added amounts to about 0.45 per cent of the dry pyro and about 0.4 per cent of the finished powder.

The charge is then mixed again for about 30 minutes. During this time the pyro becomes partially dissolved or colloided by the ether-alcohol mixture. It is formed into a cylindrical cake or block in a hydraulic blocking press and passes then to the straining presses.

(h) **Pressing.**—

(1) **Strainer presses.**—The colloid block is placed in a strainer press whose bottom plate is perforated with 3/32″ holes. The

colloid is forced through these holes under a pressure of about 1300 pounds per square inch applied by a piston descending from above. The colloid emerges in small cords much like macaroni. This press is therefore frequently called the macaroni press. The pressing and straining the colloid receives here gives it a more thorough mixing and greater homogeneity. The colloid as it emerges from the strainer press is a rather tenacious translucent material which has a uniform consistency. The cords of the colloid pass from the strainer press into a blocking press, directly below, and are again pressed into a block.

(2) **Die presses.**—The die presses in which the colloid is formed into powder grains are similar to the strainer presses, except that they are placed horizontally. In the die press the colloid is forced through a die carried in a diaphragm at the end of the press. The die consists of a tubular channel, the outside opening of which is somewhat smaller than the inner one. In the inner end of the die is a very small perforated plate which carries long pins which give the finished grain its perforations. In some of the smaller granulations there is only one centrally placed pin in the die and hence only one perforation in the finished grain. For the larger powders there are seven pins in the die, one in the axis of the die and the other six spaced equally about it, and equidistant from each other.

The colloid block from the blocking press is placed in the die press and pressure is applied to force the colloid through the die. This pressure is usually from 1800 to 2500 pounds per square inch, depending upon the consistency of the colloid and the size of the die. Under this pressure the colloid is forced through the small perforated diaphragm and then closes in around the pins. It issues from the face of the die in a continuous longitudinally perforated cord, which is led to a machine cutter and there cut by revolving knives into the desired uniform lengths. The cord of powder passing from the die to the cutter is inspected for imperfections. If these are found, the imperfect section is broken out of the cord by hand and discarded. The grains falling from the cutters are also inspected and any distorted or faulty grains are removed.

The "green" powder as it comes from the die press is fairly soft because of the large excess of solvents which it contains.

When the solvents are evaporated out the grains become hard and translucent; in physical characteristics they are then much like horn.

(i) **Recovery of solvents.**—The first step in the drying of powder consists in rapid heating in a closed container to evaporate a portion of the excess solvents, which are then recondensed for further use. This process is generally called *solvent recovery.* There are several different forms of apparatus used for this purpose, but the principle is the same in all cases. After the green powder has been charged into the recovery container, a current of preheated air is passed through the powder and a part of the excess solvents are quickly volatilized. The air then passes through a cooling system where the vaporized solvents are condensed and are drawn off as liquid, to be separated into ether and alcohol by distillation. Most of the solvent thus recovered is ether, since that is more volatile than alcohol. The air, after being cooled to condense the solvents, passes again through the preheaters and so once more through the cycle. The temperature of the air passing through the powder during recovery of solvents varies from about 35° C. to 39° C. The powder is subjected to the process for four or five days.

(j) **Drying.**—The final drying of the powder is usually carried out by a gradual process of air drying in large dry-houses. There are several different types of dry-houses, but all are so designed as to permit the maintaining of a constant temperature and a constant circulation of air. The powder is placed in bins through which air is circulated. During the first 60 days the powder is dried without heating. The temperature of the circulating air is then raised usually to 40° C. and maintained at that temperature during the remainder of the drying period, which may continue through two to four months longer. The duration of the drying period will depend upon the total amount of volatiles to be evaporated from the powder, and upon the size of the grain. The percentage of total volatiles remaining in the powder is determined by analysis from time to time, as the estimated completion of drying approaches. When the total amount of volatiles has been reduced to the proper figure, the grain will have been dried to the desired dimensions and speed of burning. The powder shrinks materially during drying and this must be taken into account in determining

the dimensions of the die in which the grain is formed in the pressing operation. The final dimensions of the grain exert an important influence upon the ballistic characteristics of the powder in a given gun. This point will be referred to again later.

The percentage of volatiles remaining in each powder after drying varies from about 3 per cent to 7 per cent, being greater in the larger granulations.

Water-dried powders.—Nitrocellulose smokeless powders can also be dried, that is, have their excess volatiles removed, by circulating through them warm water instead of warm air. The temperatures used in water drying are somewhat higher than in air drying, and the process is completed much more quickly. A short air drying suffices after the water treatment is completed.

(k) **Blending.**—The poacher lots maintain their identity until they have passed through the dry house. For convenience in assigning powders to ships, and for the maximum uniformity in the charges assigned to each ship, it is desirable to reduce as much as possible the number of lots or indexes of powder. Each index consists of 100,000 pounds of powder for guns above 3″, and usually of 50,000 pounds for 3″ and smaller guns. In order to make up one index, it is therefore necessary to use a number of poacher lots, and these must be blended in order to give uniformity throughout the index.

After the drying is completed and before blending, the powder is exposed to the atmosphere for from 24 to 60 hours in order to insure that surface moisture is as nearly uniform as possible.

Blending is usually carried out in blending towers. The tower consists of a series of bins arranged in groups, with groups one above the other. The bins of each group are usually arranged in polygons and each bin has a trap or gate valve in the center of its group. In blending, the top group of bins is filled with powders from different poacher lots. The traps or gate valves are opened simultaneously and the powder from the bins falls to the next group in one stream, which separates about equally into the bins of the next lower group. This operation is continued from group to group and the powder is finally drawn off through a hopper at the bottom of the blending tower into the powder boxes in which it is shipped to the ammunition depots. The boxes are usually run under the hopper on scales and are weighed as they

are filled. They are then sealed with airtight covers and marked with the factory identification number, the weight and the date of packing. During the packing a firing sample is selected for proof of the lot in a gun of the type and caliber for which it is intended. If the lot passes proof and chemical specifications and is accepted by the Bureau of Ordnance, it is assigned an index number by the bureau. It retains that index number while it is in service.

SUMMARY.

The process of manufacture may be summarized as follows:

(a) *Picking.*—To grind and to remove lumps and foreign matter.

(b) *Drying.*—Dried for about 12 hours at about 100° C. to reduce moisture contents to less than 1 per cent before nitration.

(c) *Mixing acids.*—Fortifying "spent acids" to required strength before delivery to nitrators.

(d) *Nitrating.*—Thirty pounds of cotton immersed in H_2SO_4, and HNO_3 for about 20 minutes, when it contains 12.60 ± 0.10 per cent of nitrogen.

(e) *Purifying.*—(1) *Drowning.*—To remove free acids.

(2) *Preliminary boiling.*—Boil at temperatures 80° and 100° C. to further remove free acids.

(3) *Pulping.*—Ground for about eight hours in contact with water, to break up tubular cotton fibers.

(4) *Poaching.*—Boiled in water with carbonate of soda for about six hours, allowed to settle one hour, then water is replaced with fresh water. The boiling is repeated for two hours, then for four one-hour periods, using fresh water for each boiling. Washed one-half hour and drained one hour (without heat), repeated 10 times. After poaching a sample is sent to laboratory for testing.

(f) *Dehydrating.*—Water is forced out of pyro by forcing alcohol into it under pressure. Charge is then caked under pressure.

(g) *Mixing.*—A charge of dehydrated pyro is ground for 20 minutes to break it up thoroughly. The ether constituent of the solvent and the diphenylamine are then added and charge mixed for 30 minutes. It is now a colloid and is again formed into cakes for next process.

(h) *Pressing.*—(1) *Strainer presses.*—Under a pressure of about 1300 pounds, the cakes are forced through 3/32″ holes in strainer press. The cords as they issue pass directly to a blocking press below and are again formed into a block.

(2) *Die presses.*—Under a pressure from 1800 to 2500 pounds, the cakes are forced through the die press, from which it emerges in rods of the desired diameter with seven perforations (one in small-grain powder). The rods, as they issue from press, are cut into grains of the desired length by revolving knives.

(i) *Solvent recovery.*—The green powder is submitted to hot air for four to five days at a temperature of 35° C. to 39° C. The solvents having been vaporized are recovered by condensation.

(j) *Drying.*—The green powder is dried at air temperature for about 60 days, and at 40° C. from two to four months.

(k) *Blending.*—One hundred thousand or 50,000 pounds in one charge is blended to get all the powder of one index of an even mixture, so that any two bags of equal weight will give the same initial velocity under similar conditions.

As the powder issues from the "*blending tower*" it is weighed, boxed, and sealed with airtight covers and marked with a factory identification number, the weight, and date of packing.

After proof, if satisfactory, an index number is assigned by the bureau.

43. Reworked powder.—Powders which have been subjected to conditions which have or may have impaired their stability, and remnants of indexes, are recovered for use as reworked powder.

In reworking, the old powders are ground in water by a large heavy mill, which crushes the grains and finally reduces them to a pulp similar to the fresh pyro pulp coming from the pulpers. This reworked pyro, as it may be called, is put through the same general processes as new pyro, from the poaching on to the end of the process. Reworked powders are considered nearly as good as new powders, the principal difference being that their nitration is not quite so high, and the grains are not quite so tough. Reworked powders are darker in color than new powders.

44. Smokeless powder—general discussion.—The smokeless powder resulting from the methods of manufacture described in the foregoing paragraphs is a hard, tough, translucent substance varying in color from a light lemon to a deep brown. The differ-

ences in color are due to some extent to variations in manufacture and in the water used in the purifications processes.

The nitrocellulose constituent of the powder is regarded as a mixture of ennea-nitrocellulose, $C_{24}H_{31}O_{20}(NO_2)_9$, and deca-nitrocellulose, $C_{24}H_{30}O_{20}(NO_2)_{10}$. These nitrocelluloses are the highest which are soluble in the ether-alcohol mixture.

The powder burns regularly and progressively, leaving an almost negligible quantity of ash. The progress of the reaction of the powder in a gun may be divided into three stages: *ignition, inflammation*, and *combustion*.

(a) **Ignition.**—Ignition is the setting on fire of a part of the grain or charge. It results from the application of sufficient heat to raise the temperature of the powder to the point where rapid chemical decomposition takes place. When the powder is thus ignited, the reaction proceeds without further external aid and rapid evolution of gases, with heat and flame, results. The time necessary for ignition varies with the kind of powder and its condition. A dry powder ignites more readily than a damp powder; a rough grain more readily than a smooth grain. Black powder ignites more readily than smokeless powder, although its ignition temperature is higher. This is because the heat conductivity of smokeless powder is greater than that of black powder, and the local heating therefore takes place more slowly. For this reason, charges of smokeless powder are ignited through small ignition charges of black powder, the burning of which envelops the grains of the smokeless powder with an intense and somewhat sustained flame. The ignition charges themselves are ignited by a flame from a primer which is fired by electricity or by percussion. In cartridge-case guns the ignition charge of black powder is contained in a magazine attached to, or forming a part of, the primer proper.

(b) **Inflammation.**—Inflammation is the spreading and development of the flame over the whole surface of the grain or charge. The burning of smokeless powder takes place always upon the surface, a new layer becoming ignited as the preceding one burns away. Each charge or section of smokeless powder is provided with a sufficient ignition charge of black powder to produce throughout the powder chamber a volume of flame which will surround each grain of smokeless powder and inflame its

surface. This inflammation is aided by the pressure due to the gases from the ignition charge.

(c) **Combustion.**—Combustion is the burning of the inflamed powder from layer to layer upon the surface. In the absence of pressure, for instance in the open air, this combustion is very slow. When the powder is burned in a gun, or in other confined space, the combustion is greatly accelerated, as has previously been pointed out, due to the pressure of the resulting heated gases upon the surface of the grains.

The rate of combustion depends not only upon the pressure of the gases surrounding the burning powder, but also upon the temperature of these gases. Their temperature depends upon the composition of the powder and the conditions under which the combustion takes place. The rate of combustion of different powders varies also with the amount of residual solvent remaining in the powder after drying. The greater the percentage of volatiles, the slower is the rate of burning.

The progressively burning quality of smokeless powder is made use of in controlling the evolution of gases, to get the desired regulation of pressures. This is done by varying the size and shape of the grains, which will determine the rate at which gases are evolved, other conditions being equal, since it is evident that with equal rates of combustion the rate of evolution of gases will be proportional to the area over which combustion is taking place.

The desirability of having a form of grain which presents constantly increasing burning surfaces during the progress of combustion has previously been referred to. Solid grains give the least progressive form, since their burning surface constantly decreases as combustion proceeds inward from the surface. The best form of solid grain is a flat strip, since its burning surface decreases least rapidly. As previously stated, the form of grain adopted by the United States Navy to give progressive burning is the perforated cylinder. Cylindrical grains with single central perforation are used in many small-arms powders and powders for small-caliber guns. Single perforated grains have a practically constant burning surface. A cylindrical grain with seven perforations arranged as previously described under the manufacture of smokeless powder is used in the larger caliber United States Navy guns. The cross-section form of this type of grain is shown in Fig. A.

The principal dimension used in designing powder grains is the least dimension between burning surfaces. Since the burning takes place at equal rates in each direction, under equal conditions, the time taken to burn through this least dimension determines in general the time occupied by the combustion of the whole grain.

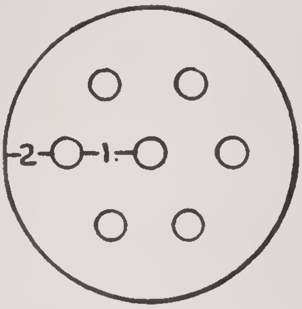


FIG. A.—ORIGINAL GRAIN.
1. Inner Web Thickness.
2. Outer Web Thickness.

This dimension is called the "web thickness." In solid grains the web thickness is the least dimension of the grain; for single perforated cylindrical grains the web thickness of $\frac{D-d}{2}$, where D is the diameter of the grain and d the diameter of the perforation. For multi-perforated cylindrical grains the web thickness is $\frac{D-3d}{4}$, where D is the diameter of the grain and d the diameter of the perforations. Multi-perforated cylindrical grains have an increasing burning surface, since combustion proceeds from the outer diameter inward, and from the perforations outward. These

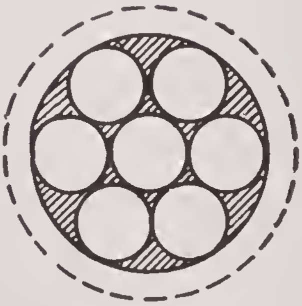


FIG. B.—PARTLY CONSUMED.
Hatched Areas Show Slivers.

grains therefore give progressively increasing volumes of gas up to the instant when the inner burning surfaces meet and the grain separates into solid slivers.

Fig. B illustrates the progress of combustion in a multi-per-

forated grain up to the instant when slivers are formed. From this instant the burning surface decreases and the powder burns less progressively. In firing reduced charges, sometimes used for target practice in order to reduce wear of the gun due to erosion, the combustion of the grain is often incomplete due to the lower pressures generated, and unburned slivers of powder are frequently found outside the gun, being blown out by the rush of powder gases when the projectile emerges from the muzzle. This, however, does not affect the uniformity of the pressures and velocities attained, since the effective combustion will have been completed when the projectile leaves the gun.

By density of powder is meant its specific gravity, or the ratio of the weight of a given volume of powder to the weight of an equal volume of water, at the standard temperature. The density of large-grained powders may be determined by weighing a grain of the powder in air and in water. For small grains the mercurial densimeter may be used and correction applied to obtain weight in water, rather than in mercury. The difference of the weights in air and water is the weight of a volume of water equal to the volume of the grain.

The density is then the weight in air divided by the difference of the weights.

The density of smokeless powders varies from 1.54 to 1.62.

The density of a grain of nitrocellulose powder is practically constant so long as it contains a uniform quantity of solvent and moisture. It has been found that the density or specific gravity varies inversely as the total amount of volatiles, and is represented by the following formula:

$$\text{Sp. gr.} = \frac{12.3728 - 0.132\,\text{T. V.}}{7.4} \text{ or} = 1.672 - (.0178 \times \text{T. V.}) \qquad (2)$$

where T. V. is the percentage of total volatiles. The curve is shown in Fig. C.

Since the amount of remaining volatiles is greater for the larger web powders, in general the density of the powder may be said to decrease as the web increases.

45. Products of combustion of nitrocellulose powder.—The decomposition of our nitrocellulose powders in burning is usually represented by the following equation:

$$C_{24}H_{30}(NO_2)_{10}O_{20} = 12CO_2 + 12CO + 4H_2O + 11H + 5N_2.$$

This represents a reaction which is complete for a nitrocellulose of 12.75 per cent nitration. It does not take into account the reactions due to the presence of the volatiles or the stabilizer. It is deduced from theoretical considerations and from the study of products of explosion made in laboratory apparatus in which only a small amount of explosive is used, the density of loading being therefore small, and in which the gases have been considerably cooled before examination. That the actual products of com-

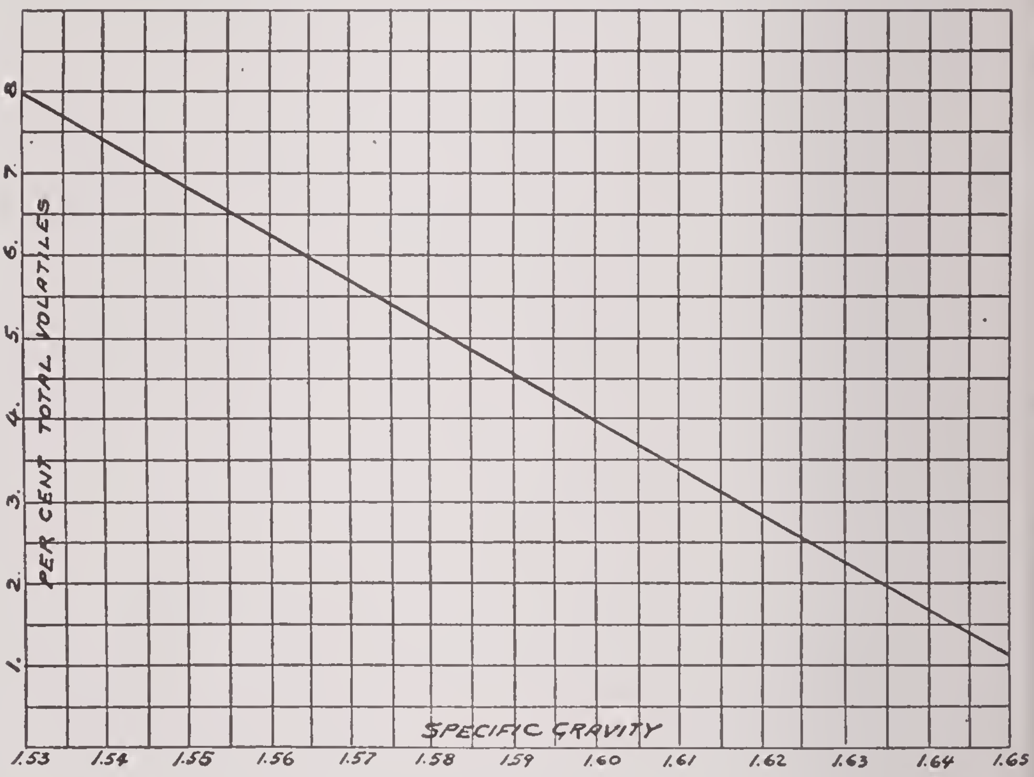


FIG. C.

bustion differ considerably from those above represented is evidenced by the deep orange-colored cloud of gas accompanying the discharge of the gun. This color is due to oxides of nitrogen, which are not accounted for in the theoretical equation. Since the actual products of combustion are not all colorless gases the powder cannot be called truly "smokeless." This term has been used in a relative sense to distinguish the modern powders from their predecessors which gave off dense clouds of white smoke. The gases from "smokeless" powders are much less opaque and are dissipated much more rapidly. A small cloud of white smoke,

due to the black powder ignition charge, is usually readily distinguished in the gas from a gun firing smokeless powder.

It will be noted that carbon monoxide forms a considerable portion of the products of combustion in the above reaction. The effect of this upon the temperature of the gases during the explosive reaction has already been pointed out, as has also the possibility of "flareback" due to ignition of this inflammable gas when mixed with air.

46. Stability of nitrocellulose powders.—Powders containing nitrocellulose are subject to a very gradual chemical decomposition which may in time be a source of danger unless measures are taken to arrest or check such action. From its nature nitrocellulose is, like many explosive compounds, in a state of unstable chemical equilibrium and is readily acted upon unfavorably by impurities which may be present with it. If decomposition takes place in any particle the decomposition products will include nitrogen oxides which have an acid reaction and will facilitate further decomposition. The reaction occurring will be accelerated for this reason and a progressive decomposition will result. The decomposition will be greatly facilitated by heat and by the presence of moisture.

During manufacture every precaution is taken to insure the absence of impurities in the raw materials and the removal of impurities during the various courses of purification. The principal impurities removed during manufacture are the sulphates, which are formed as by-products, so to speak, of the nitrating reaction, and the free acids remaining after nitration. The addition of the stabilizing substance, diphenylamine, is the means taken to counteract any decomposition which may begin in the finished powder. The way in which diphenylamine arrests decomposition through neutralizing the acid decomposition products has already been mentioned. Progressive decomposition cannot occur until all of the diphenylamine in the powder has been used up by combining with the acids. The use of diphenylamine has greatly increased the stability life of our powders and the limits of its effectiveness have not yet been reached.

The presence of residual volatiles in the powder also tends to retard possible decomposition. For this reason, as well as to avoid change in ballistic qualities through change in the rate of

combustion, every effort is made to prevent the loss of volatiles from the finished powder.

Excessive heat will have a most unfavorable influence upon the stability of the powder. At temperatures below, say, 60° F., the stability is not appreciably affected. At temperatures above 70° F. the rate of decomposition rises quickly with rises in temperature, becoming high at 90° F. and dangerously accelerated at temperatures over 100° F. Precautions are therefore taken to insure the maintenance of a uniformly low temperature as far as possible in the magazines in which powder is kept on shipboard and elsewhere.

Since the presence of moisture favors decomposition, the containers in which the powder is stowed are made airtight and every effort is taken, through care in handling, to maintain their tightness. A leaky container may not only admit undesirable moist air to the powder, but may permit the loss of volatiles through evaporation, especially if the air in the container is changed through alternate expansion and contraction due to changes in temperature.

The Navy Regulations prescribe a rigid series of periodical tests whereby the stability of each index of powder on board ship or elsewhere may be observed, and also require the strict exercise of the precautions necessary to insure the longest possible maintenance of a stable condition. Under normal conditions of storage any possible decomposition is very slow and the tests prescribed will give unmistakable evidence of decomposition long before such decomposition becomes dangerously advanced. This fact must, however, not influence anyone charged with the care of powder to relax in any degree the vigilance with which the powder is observed and safeguarded from unfavorable conditions.

47. Loss of volatiles.—Loss of volatiles, through leaky containers or otherwise, will increase the rate of combustion of the powder; hence it will increase the pressure in the gun due to a given weight of charge. It is possible that a charge which has lost volatiles to a considerable extent may produce dangerously high pressure when fired. Such powder has sometimes been said to be *dynamically dangerous*. "Ballistically dangerous" would probably be a more descriptive term. It is readily seen that the same precautions—tight containers and uniformly low tempera-

tures—which guard against the development of "unstable or chemically dangerous" powders will also guard against the development of *ballistically dangerous* powders. Under normal conditions of storage powders will not lose volatiles to any appreciable degree.

A powder which may have become dangerous chemically through partial decomposition is not dangerous ballistically since a part of the decomposition, which should take place in the gun with sudden evolution of heated gases, has already taken place and the powder has lost a corresponding number of heat units.

(2) GUNCOTTON.

48. (a) **Properties.**—Guncotton is composed of nitrocelluloses of higher degrees of nitration than those which are used for smokeless powders. The nitration of military guncottons is over 12.9 per cent. Guncotton is very much like ordinary white cotton when pure. When wet it retains its chemical stability for long periods during storage and is quite insensitive to flame, shock, or friction. It can, however, be detonated, even when wet, by means of a proper detonator and booster. The means usually used for initiating detonation in wet guncotton are a fulminate detonator acting through a booster or "primer" of TNT or dry guncotton.

Dry guncotton is a powerful explosive and is much more sensitive than wet guncotton. It requires special care in storage for this reason and for the reason that it is not as stable chemically as wet guncotton.

(b) **Uses.**—Wet guncotton was for many years the principal explosive used in various military services for torpedoes, mines, and demolition charges. It was used for these purposes in the United States Navy for a long period, but is no longer being manufactured for such use, since the adoption of TNT.

Dry guncotton is used as a primer for wet guncotton charges; and as one of the components in certain types of detonators and cannon primers, solely as a flame producer to be ignited from an electric bridge wire.

(c) **Manufacture.**—The manufacture of guncotton is similar to the manufacture of nitrocellulose for smokeless powder, except that the nitrating process is more sustained in order to produce a higher percentage of nitration and differs somewhat in other

details. The nitrated cotton passes through a purification process consisting of washing, preliminary boiling, pulping, and poaching similar to the process used in the purification of nitrocellulose for powder. After purification the guncotton is usually pressed into blocks of the desired form. Wet guncotton contains water in the amount of about 25 per cent of the dry weight of the guncotton. This percentage is maintained during storage by the addition of distilled water from time to time as required.

(3) BLACK POWDER.

49. (a) **Properties.**—The composition of black powder varies somewhat, depending upon the use for what it is intended. The usual composition, however, is about as follows: Saltpeter (potassium nitrate), 75 per cent; charcoal, 15 per cent; sulphur, 10 per cent. The form of the powder also differs, depending upon the use for which it is intended. When made up in grains, the powder has a somewhat glazed surface and is free from dust. For certain special purposes, for instance in fuses, a very fine black powder known as fuse powder or meal powder is used.

(b) **Manufacture.**—The ingredients are powdered by grinding separately before mixing. A preliminary mixing is then given, usually in a rotating wooden drum containing lignum vitæ balls. The mixture is usually thoroughly incorporated in a mill in which the mixture is ground and worked under large slow-moving rollers. In this process the mixture cakes somewhat and it is therefore broken by hand before passing to the press. In the press the powder mixture is subjected to high pressure to produce a dense, hard mass. The pressed mass is broken up and passed through a granulating mill where it is broken into smaller grains by passing through several pairs of rolls. These grains are separated into different sizes by passing through sieves. The grains are glazed by being tumbled about in rotating wooden drums. Some powders, especially larger grain sizes, have graphite added to facilitate glazing. After glazing the powder is usually dried under moderate temperatures.

(c) **Uses.**—Black powder is used in the United States Navy for (1) ignition charges, both in pads sewed into the bags containing smokeless powder, and in brass cannon primers; (2) in powder trains for fuses and similar devices, where the powder is

loose if intended for instantaneous transmission of flame, and pressed hard if intended for a delay or time train; (3) as the bursting charge in several classes of projectiles, such as common projectiles, shrapnel, and star shell, where extreme disruptive force is not needed or where the bursting charge is intended only to open the shell and discharge its contents; (4) for blank charges in saluting guns; (5) for torpedo impulse charges.

(4) TRINITROTOLUENE (TNT).

50. (a) **Properties.**—Trinitrotoluene, frequently called trinitrotoluol, or TNT, is a crystalline solid of the formula $C_6H_2(NO_2)_3CH_3$. When pure it has a pale yellow color and a melting point of about 80.5° C. When exposed to light its color becomes darker, approaching a dark red, and its melting point is somewhat lowered. Two grades of TNT are used in the United States Navy, one of high melting point which is called "Grade A" or "refined" TNT, and one of lower melting point which is termed "Grade B" or "crude" TNT. The other principal physical differences in these two grades are that Grade A TNT has lighter color, better crystalline form and is freer running. Grade B TNT has about the color and consistency of brown sugar and it tends to agglomerate or pack. Both grades can readily be melted and poured into containers to solidify. When TNT is cast its color changes to a deep yellow brown. TNT may also be run into cold water from the molten state. It will then assume the form of pellets.

TNT is nearly insoluble in water. It is practically non-hygroscopic and absorbs moisture only to a negligible degree when exposed to damp atmosphere. A cast charge of TNT is impervious to water if its surface is unbroken. TNT in any form may remain under water or exposed to water for long periods without harmful effect, and, when dried out, should be as efficient as before. Water present with granular TNT will, however, affect the readiness and completeness with which it is detonated. When the amount of water reaches about 15 per cent by weight, the granular TNT cannot be detonated with the detonators usually used.

TNT is neutral in its reaction and does not form sensitive compounds by reaction upon metals, as does picric acid. It is

chemically stable and will retain its stability for long periods even under variable and unfavorable conditions of storage. In fact, its stability life seems almost unlimited.

TNT is quite insensitive to impact, friction, and pressure. When it is ignited in the open it burns slowly, giving off a dense, black smoke. If ignited confined, the rate of combustion increases and explosive effects result. TNT can be detonated only by the application of a powerful shock from another explosive detonated in contact with it or in close proximity to it. The safety with which TNT can be handled and transported has recommended it highly for various military uses. Like all explosives, it must however be treated at all times with every reasonable precaution.

"Grade A" TNT is detonated more readily than "Grade B" TNT, and granular or pelleted TNT is much easier to detonate than the cast form. A granular or pelleted booster charge of "Grade A" TNT is therefore usually used in detonating charges of cast TNT.

The disruptive force of TNT has been stated as roughly 10 per cent less than that of picric acid, and slightly greater than that of wet guncotton. When detonation is complete it gives off a considerable volume of black smoke, due to the uncombined carbon resulting from the reaction. When detonation is incomplete the smoke given off is yellow or yellow gray due to the presence of unconsumed TNT. The rate of detonation of TNT is about 7000 meters per second.

Unless very pure, TNT usually contains a certain proportion of isomers (that is, substances having the same chemical formula but with a different molecular arrangement). These isomers have a lower melting point than the pure TNT and they therefore tend to segregate and exude, especially from "crude" TNT, and more particularly from cast charges. This exudation increases with increased temperature. The appearance of these isomers, exuding from TNT containers as dark brown oily liquids, is not uncommon and need not cause alarm. The isomers are detonated less readily than pure TNT and their presence therefore affects the readiness with which the whole charge is detonated, but it appears that they take part in the reaction when the whole charge detonates. The isomers are inflammable to about the same extent as TNT and are not more sensitive to impact or friction. Their presence does not appear to affect chemical stability.

(b) **Manufacture.**—Trinitrotoluene is produced by the nitration of toluene, $C_6H_5(CH_3)$. This substance is one of the oily liquids present in coal tar and separated from it by fractional distillation.

The nitration is carried out by treating toluene with a mixture of nitric and sulphuric acids at a temperature of about 160° F. The reaction proceeds in steps, the initial product being mononitrotoluene, which by further nitration is converted to dinitrotoluene, and finally to trinitrotoluene. The progressive nitration is sometimes carried out in a single container or kettle, the successive steps being brought about by the addition of fresh acids to strengthen or fortify the mixture; it is sometimes carried out by conducting the three steps in three sets of nitrators, the third step requiring the strongest acids.

After the spent acid from the last step in the nitration has been drained off the crude trinitrotoluene is crystallized by melting in strong sulphuric acid and cooling. The acid carries off impurities in solution and the trinitrotoluene crystallizes out in cooling. The crude trinitrotoluene is washed several times with hot water until the remaining acids are removed. It is then melted in a steam-jacketed pan and heated until the water is driven off, and recrystallized by cooling while being stirred constantly.

Purification and recrystallization is often carried out by treating with various solvents other than sulphuric acid, such as alcohol, alcohol and carbon tetrachloride, and sodium sulphite solution. The methods used differ with various manufacturers.

During the manufacture of trinitrotoluene and its subsequent handling workers are often subject to a slow poisoning through inhalation of vapors and dust, or absorption of material through the skin. The effect of this poisoning usually wears off when exposure is stopped and can be prevented or much reduced by the wearing of gloves and protective clothing, and by washing the clothing and body carefully.

(c) **Uses.**—Trinitrotoluene is used in the United States Navy as the main charge in the later types of mines and torpedoes, in depth charges and in aero-bombs. For these purposes "Grade B" trinitrotoluene is used. It is cast into the explosive chamber and in this state has a density of about 1.5.

"Grade A" trinitrotoluene is used in crystalline form with a density of about 1.0 for primer or booster charges in the weapons

named above. The weight of the booster charge is usually about 1.5 to 2.0 per cent of the weight of the main charge. Crystalline "Grade A" trinitrotoluene has also been used for booster charges in certain types of fuses.

Various high-explosive projectiles not intended for use against armor have been loaded with trinitrotoluene bursting charges. "Grade A" trinitrotoluene has been used for this purpose, in some cases in compressed crystalline form, in other cases cast.

(5) TRINITROXYLENE (TNX).

51. Trinitroxylene, or TNX, $C_6H(NO_2)_3(CH_3)_2$, is produced by the nitration of xylene, $C_6H_4(CH_3)_2$, which like toluene is obtained from coal tar. This substance is a brown crystalline solid, whose physical and chemical characteristics are analogous to those of TNT, and whose stability and safety are comparable to those of the latter. It is detonated with more difficulty than TNT, but in mixture with the latter in proper proportions gives an explosive substance which is practically as satisfactory for cast charges.

The use of this mixture, sometimes called toxyl, was developed for and under the Bureau of Ordnance during the World War, in order to conserve the supply of TNT.

(6) PICRIC ACID.

52. Trinitrophenol or picric acid, $C_6H_2(NO_2)_3 \cdot OH$ is derived from phenol, $C_6H_5 \cdot OH$, otherwise known as carbolic acid. It is a yellow crystalline solid of good chemical stability and highly explosive properties when properly detonated. It has good chemical stability except that it is prone to act upon metals to form metallic picrates which are very sensitive explosive substances.

(a) **Manufacture.**—Picric acid manufacture is usually carried out in two stages. In the first stage phenol is treated with sulphuric acid. This sulphonation results in the production of phenolsulphonic acid, which is nitrated with nitric acid to form trinitrophenol. The product is carefully purified by washing with water.

(b) **Uses.**—Picric acid has been used as a booster material in various types of fuses and has been employed by various countries as a bursting charge for projectiles. Ammonium picrate,

$C_6H_2(NO_2)_3ONH_4$, has been preferred by some for the latter purpose, since it does not form the sensitive metallic picrates.

(7) TETRYL.

53. Tetryl, or tri-nitro-phenyl-methyl-nitramine, $C_6H_2(NO_2)_3N(CH_3)(NO_2)$, a yellow crystalline explosive substance, sometimes called tetra-nitro-methyl-aniline, is usually produced by the sulphonation and nitration of dimethylaniline, which is produced from aniline and methyl alcohol. The product is purified by washing in water, drying and recrystallizing from hot benzol.

Tetryl is more sensitive than TNT or picric acid and is much used for boosters and detonating trains in various types of detonating fuses.

(8) FULMINATE OF MERCURY.

54. Fulminate of mercury, $HgO_2C_2N_2$, is a fine yellowish-white crystalline explosive substance, which is highly sensitive to heat, impact, and friction. It is insensitive when wet and is usually handled wet in manufacture. It is produced by dissolving mercury in strong nitric acid and running the solution into alcohol. The product is thoroughly washed and is usually dried only shortly before loading.

The sensitiveness and explosive violence of fulminate of mercury make it especially suitable for the initiation of explosive reactions in other substances. It is used in fulminate caps, usually mixed with potassium chlorate, antimony sulphide or other materials which produce a longer flame, to ignite powder charges, either directly, as in small arms, or through black powder ignition charges contained in the same primer with the cap. The use of further ignition charges of black powder in the powder bags of larger guns has already been described.

Fulminate or fulminate mixtures are also widely used in detonators of all kinds to initiate the detonation of high explosives either directly or through boosters.

CHAPTER III.

ELEMENTARY INTERIOR BALLISTICS.

Section I.—Definition and Scope.

55. **Ballistics** as a whole may be considered the study of the general system by which a projectile is fired from a gun to hit a distant target.

Evidently the study of the system may be readily divided into two branches, *i. e., exterior ballistics,* dealing with the flight of the projectile after leaving the muzzle of the gun, and *interior ballistics,* with the movement of the projectile within the gun. The connecting link between the two branches is obviously the muzzle velocity of the projectile, both direct and rotational.

56. The artillerist demands, for the purpose of exterior ballistics, a certain velocity. From the principles of interior ballistics, and the form of the gun, the weight and characteristics of the powder must be determined in order that such a muzzle velocity may be produced without undue strain on the gun. The artillerist naturally desires a maximum velocity for great range and flat trajectory; the designer must consider the strength of his gun and desires the minimum wear or erosion therein; the velocity finally agreed upon must be in the nature of a compromise between the two.

57. To determine the velocity of the projectile in the gun, with the accompanying pressures and action upon both projectile and gun, and the effect upon these pressures and velocities of changes in any of the "conditions of loading," such is the field of interior ballistics. By *"conditions of loading" are meant the powder used, the weight of charge, the density of loading, the volume and form of the powder chamber, and the weight of the projectile.*

To insure clarity in the following discussion, several elementary definitions must here be given:

58. **A gun** is a mechanical device, composed essentially of a tube, closed at one end at the moment of firing, capable of containing a projectile and a propelling charge and of so controlling the explosion of the charge as to discharge the projectile with a high velocity.

The gun must fulfil the following conditions:

1. *Mechanical conditions.*—Its construction must be such as to withstand the action of the rapid burning of the propelling charge. After the stresses upon the gun have been determined by the processes of interior ballistics, its construction is governed by the study of the "elastic strength of guns."

2. *Ballistic conditions.*—The gun must produce a given ballistic result, *i. e.*, must deliver a certain weight of projectile at a given muzzle velocity with minimum possible stresses on the gun. These conditions are the special field of the study of interior ballistics.

3. *Service conditions.*—The gun must easily fulfil the necessities of the service relating to the working of the breech, the loading, training, and aiming of the gun. The last two, however, are more properly matters of the gun mount rather than the gun itself.

59. *The powder chamber is that portion of the gun wherein the powder is contained before the firing of the gun.* Since the projectile is seated at the forward end of the chamber and the gun is closed at the rear end by the breechblock, it may be seen that at the instant of firing and until the movement of the projectile, the powder chamber becomes the container of the powder gases. It may, therefore, be expected that the volume of the powder chamber plays an important part in the study of interior ballistics.

The bore of the gun is that part wherein the gun is of a uniform diameter, from muzzle to powder chamber. The length of the bore represents the total travel of the projectile in the gun.

60. *The "density of loading" is the ratio of the weight of the charge to the weight of a volume of water at standard temperature sufficient to fill the powder chamber.* One pound of water occupies 27.68 cubic inches; hence, if S is the volume of the powder chamber, the equivalent weight of water is $\frac{S}{27.68}$ pounds. Now as $\tilde{\omega}$ is the weight of the powder charge, $\frac{\tilde{\omega}}{\frac{S}{27.68}}$ is the density of loading, expressed usually as Δ. Then, simplifying, we have

$$\Delta = \frac{27.68\,\tilde{\omega}}{S}. \qquad (1)$$

61. Known elements.—In proceeding to the mathematical examination of the action of the gun, the following elements are considered for the moment known and fixed. Once their interrelation is determined, then the effect of variation in one or more may be determined. The notation used is that generally employed in works on interior ballistics.

Elements of the gun:

u, travel of the projectile in the bore, in feet.

A, area of the cross-section of the bore, in square inches.

S, volume of the powder chamber, in cubic inches.

Elements of the projectile:

w, weight of the projectile, in pounds. (It is to be noted that in interior ballistics its shape and contour are of no importance save that it must close the bore when loaded in the gun.)

Elements of the charge:

$\tilde{\omega}$, weight of the charge, in pounds.

Δ, density of loading.

Unknown elements, or elements physically measured as a result of actual firing—used as check on calculated results:

V, velocity, in feet per second.

P, maximum pressure in the bore, in tons per square inch.

62. Mathematical analysis, based upon certain fundamental assumptions, allows the deduction of various formulas concerning these elements, from which the action of the gun may be predicted. Such formulas give the interrelation of the elements of pressure, velocity, travel of the projectile, form of chamber and bore, so that, when certain of these elements are known, the remainder may be found.

63. The uses of these formulas may be appreciated.

First, in the design of the gun. Given the desired muzzle velocity, and the limiting maximum pressure allowable in the gun (determined from study of gun construction); the volume of powder chamber and the weight of charge may be determined. From these the pressures existing successively in the bore as the projectile travels down the gun may be found, and the gun may then be constructed so as to afford sufficient strength throughout its length.

Second, in the design of the powder. From the action, as regards pressures and velocities, of a powder in one type of gun,

the most suitable powder may be designed for a gun of similar proportions but of different caliber.

Third, in the interchangeability of powder. With the results of firing in one gun, the action of the same powder in another type of gun may be predicted.

Fourth, and generally, the resultant changes to be expected from variation, with a certain gun and powder, of any of the several elements, *i. e.,* change of weight of powder charge, and of resultant pressures, necessary to produce standard muzzle velocity when the weight of the projectile is altered; reduction of weight of powder charge to produce a standard reduced velocity; and similar problems.

64. The results obtained by the use of the formulas are not infallible, but in general are close approximations to actual results obtained on firing with elements calculated from the formulas. Calculated results are always tested by actual firing at the proving ground, to insure against inaccuracy. The calculations, however, provide a starting point for such tests. When information is desired in advance of any possible proof work; as in planning ammunition stowage and loading arrangements aboard new vessels, necessitating knowledge of weight and volume of charges; and, as above, in designing guns or powders, invaluable data are afforded by the application of interior ballistics formulas.

In other words, while the results obtained from theory are not to be regarded as *final* without proof, yet the knowledge of the principles of interior ballistics is and has been vitally necessary to the development of naval ordnance.

Section II.—Fitting the Powder to the Gun.

65. As has been shown in the preceding chapter, smokeless powder, even though made of a standard nitration and uniform shape of grain, may be so manufactured, with different sizes of grain, and therefore different web thicknesses, that different speeds of burning may be obtained.

66. When the powder charge in a gun burns, a large quantity of highly heated gases is formed. For a given weight of powder, the total quantity by weight of such gases is constant, and is equal to the weight of the powder charge, since all of the smokeless powder is converted into gas. Now, if the powder charge is entirely consumed before the projectile moves, the container for

these gases is evidently the powder chamber only, and the large quantity of the gases, confined within the chamber and at a high temperature, tends to produce pressures so high as to endanger the gun. Hence, if all of the charge is consumed before motion of the projectile begins, but a small charge may be used with safety and the total amount of gases, or the total energy of the powder charge, must be correspondingly low.

If, however, the projectile commences to move after but a portion of the powder charge has been consumed, the space for expansion of the powder gases becomes greater and a larger quantity of gas may be contained without undue stress on the gun. Hence, a large powder charge may be employed and the total energy of the propelling charge for the gun may be increased. As the projectile moves, the powder is consumed, and is eventually all burned, while the projectile is in the gun, but not, as in the first instance, before the projectile has moved from its seat.

It is necessary, then, to use a powder of such speed of burning that the projectile has left its seat and moved forward before the powder is all consumed. It must be noted, however, that the speed of burning must not be so slow that any part of the powder is unconsumed when the projectile has left the gun, for obviously such remaining portion is wasted, as its gases, formed after the projectile is expelled, can exert very little if any effect upon the latter.

67. The time of burning of a powder, under a given standard pressure, is dependent upon its nitration, its remaining volatiles, the shape of the grain, and the web thickness—the latter, in a standard geometrical form of grain, dependent upon the size of the grain. Our practice is to keep nitration and shape of grain uniform, to restrict the remaining volatiles within narrow limits, defined by the size of the grain, since it is more difficult to drive out the volatiles from the larger grains, and to obtain the variation in speed of burning by using different sizes of grains.

(Note.—In very small powder grains, owing to difficulty of manufacture, the standard multi-perforated grain is not used, a single-perforated cylindrical grain being employed.)

68. The various types of guns, with different diameters of bore and lengths in calibers, each with its own muzzle velocity, which may or may not be the same as that of other guns, present different requirements for the powder. The lengths of travel of the pro-

jectile, and consequently the times of its travel, differ largely. From this fact alone, it is seen that different powders must be used for the several types of guns. In addition, the volume of the powder chamber and the weight of the projectile introduce elements which must, as will be seen later, enter into the selection of a powder for a gun.

69. *The powder must be fitted to the gun, i. e.*, the proper or most suitable size of grain must be found, in order that we may have the desiderata noted above, a charge only partly consumed when the projectile starts to move, so that no dangerous pressures may be caused, and yet wholly consumed before the projectile leaves the muzzle, in order that the total energy of the powder may be utilized. These general ideas will be delimited more clearly later, but with this conception of the necessity of selecting the powder for the gun the analysis of the development of the pressure inside the gun may now be considered.

70. First consider the simplest case, an instantaneous combustion with an "adiabatic expansion." *An "adiabatic expansion" is that in which the gas expands and performs work in a space impermeable to heat.* That is, the gas neither receives nor loses heat *from or to its container*, although in performing work it of course gives up its energy, in the form of heat; thus its temperature, and, since it is expanding, its pressure, both diminish.

By Charles' law,

$$PVT' = P'V'T \text{ or } \frac{PV}{P'V'} = \frac{T}{T'}. \qquad (2)$$

Or, the product of the pressure times the volume of a gas varies directly as the absolute temperature (measured from absolute zero, $-273°$ C.) of the gas. This may be expressed by putting

$$PV = RT \text{ (see Art. 19)}, \qquad (3)$$

that is, the pressure times the volume of the gas is equal to a constant times the absolute temperature of that gas. This is the fundamental equation of the gaseous state. Let $F = RT$, and consider the gas of unit weight confined in unit volume. Then $P = F$, and F is the pressure per unit surface from unit weight of gas in unit volume. When R is a constant properly computed for the gases from gun powder, then F becomes a factor dependent upon the temperature. For a given chemical composition of powder so employed in guns as to obtain a standard maximum pressure on firing, F is nearly constant and may be evaluated by experiment.

71. The fundamental equation quoted above has been found, on critical analysis by thermodynamics, to be only approximate, and the true equation becomes (using Clausius' form of the Vander Waal formula for gases and vapors),

$$P = \frac{RT}{V-a} - \frac{C(V-a)}{T(V+\beta)^2}$$

The second term disappears for high temperatures, as C is a diminishing function of T, the formula then becoming (see Art. 20)

$$P = \frac{RT}{V-a}. \tag{4}$$

This equation is for unit weight of power. If the volume V is unchanged, as the volume of the powder chamber of a gun, and the weight of powder charge is changed the equation for unit weight then becomes

$$P = \frac{RT\tilde{\omega}}{\frac{\tilde{\omega}}{\Delta} - a\tilde{\omega}}.$$

Putting $RT = F$, and simplifying,

$$P = \frac{F\Delta}{1 - a\Delta}, \tag{5}$$

which expresses the relation between the density of loading and the pressure of the gases *in instantaneous combustion*. (See Art. 20.)

72. The curve of pressure within the gun, using pressures as ordinates and travels of the projectile as abscissas, is therefore plotted as in Fig. 1. The initial pressure is given by the above equation, and the curve takes the form BM, the standard adiabatic curve of thermodynamics. The area of the curve, from the ordinate AB, represents the energy stored in the projectile, or the work done upon the projectile, at every point of the travel.

With these hypotheses, it is possible to compute these areas and to obtain approximate formulas giving the velocity of the projectile in the gun and the corresponding pressure.

73. Such for an instantaneous powder. However, it has been seen that a powder not instantaneous, but one which affords a progressive combustion, must be employed.

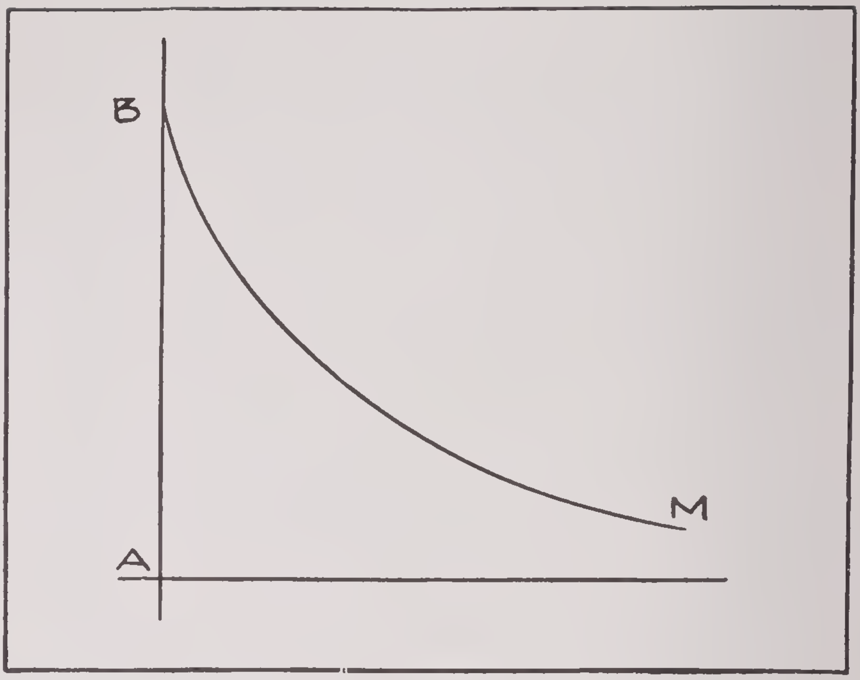


FIG. 1.

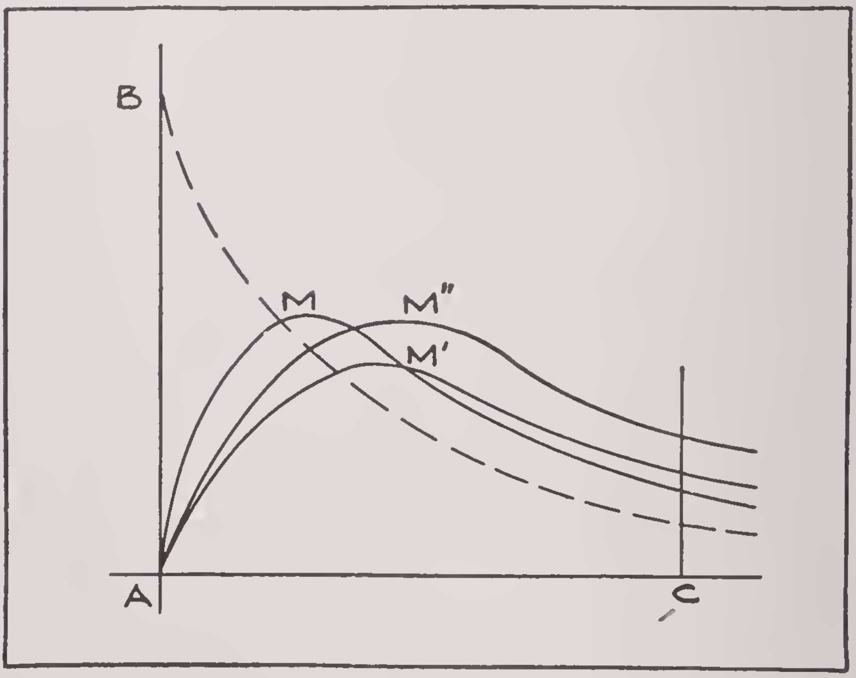


FIG. 2.

For such a powder (*i. e.,* progressive), the pressure will start from zero and will rise at first very quickly, on account of the production of gases, but soon the motion of the projectile, increasing the capacity of the powder chamber, will have the effect of reducing the pressure. For a while the increase of pressure due to the combustion of the powder will be greater than the reduction due to the motion of the projectile, and the pressure will continue to rise; but soon a time will come when both causes will be equal, and that will give the maximum pressure M. After that, the production of gas will not be sufficient to compensate for the increase in volume, the pressure will decrease, and when the powder is completely burned the curve will take the adiabatic form.

The curve of progressive powder AM is shown in full line; that of the instantaneous combustion by dotted line (Fig. 2).

74. The charges and the potential (or heat units) of the powders being the same, the curves, when indefinitely produced, will have the same area, and this is why at a certain point the curve of progressive powder runs higher than the other. If C is the muzzle of the gun, we see that the lost energy is greater with the progressive combustion, and consequently the efficiency of the powder is smaller.

Assuming that the powder to which curve AM corresponds belongs to a category whose combustion is still relatively quick, we see that the passage of the powder from instantaneous to progressive combustion results in a drop of the maximum pressure from B to M.

Should we pass, now, to a combustion still slower, with a charge of the same weight and a powder of the same composition, the maximum pressure will fall from M to M', but as the area of curve AM, infinitely expanded, equals the area of AM', also infinitely expanded, at a certain point AM' will rise above AM and more loss is indicated at C, which proves that the efficiency of the slow powder is less than that of the quicker powder. In very slow powders the grains are not entirely consumed and a greater loss of efficiency results.

Since the use of a slower powder allows the lowering of the maximum pressure, with a reduction, it is true, of the initial velocity, one is led, naturally, to inquire if, in increasing the charge of a slower powder in such a way as to keep the same

maximum pressure as that of the quicker powder, it is not possible to obtain more velocity than with the quicker powder.

This is effectively what happens. The curve of pressure takes the direction AM'', and there is a notable increase of the initial velocity in the same gun, for the average or mean pressure down the bore is greater.

It is possible, then, by using larger and larger charges of powders slower and slower, between certain limits at least, to obtain more and more velocity without going beyond the maximum pressure permissible in the gun. But the efficiency of the

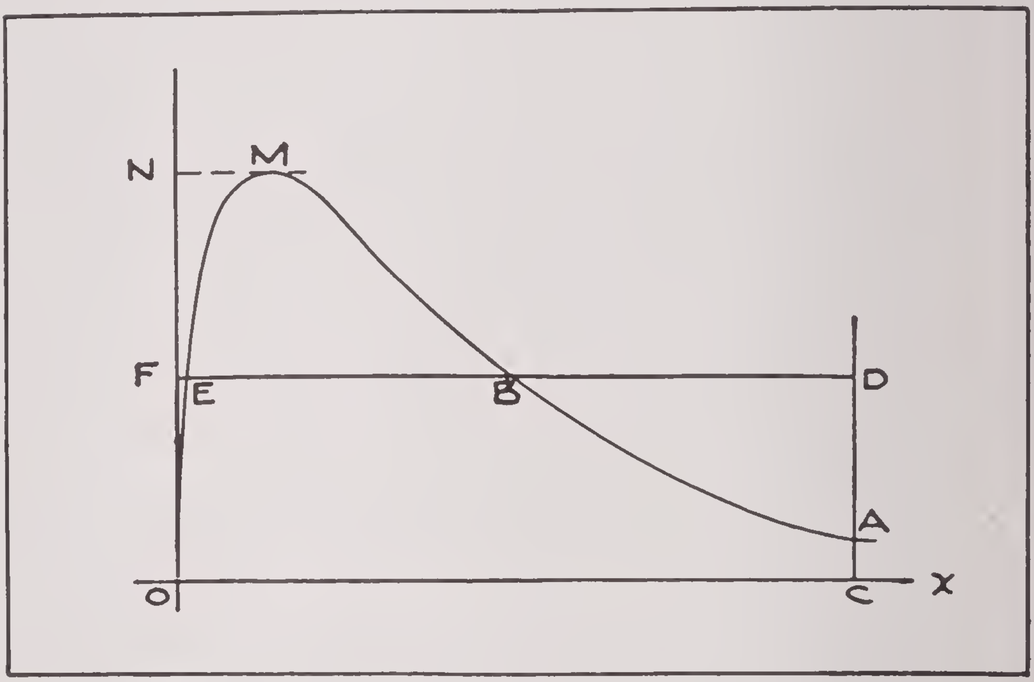


FIG. 3.

powder will be less and less, as shown by the lost pressure at the muzzle, this loss being measured by the height of the ordinate above the point C. To get more work from the powder the gun should be lengthened as much as the service conditions permit.

75. It will not be advantageous, then, to fire a slow powder in a gun not previously built for it. Besides, the regularity in the initial velocity of a gun is closely connected with the efficiency of the powder. The greater the efficiency the greater the regularity. When the efficiency is so low that unburned powder remains, considerable irregularity may result.

It will be noted that with the slower powders the point of maximum pressure moves toward the muzzle of the gun, and the

pressures throughout the subsequent travel of the projectile are higher, thus necessitating stronger construction for the chase of the gun.

76. **The mean pressure** *is an imaginary constant pressure, which, acting upon the base of the projectile during its travel in the bore, would give the projectile an initial velocity equal to that actually obtained* by the pressure acting as above described, or, in other words, would, when drawn on the curve, produce a work area equal to that of the curve of actual pressures. This follows, since for equal muzzle velocities, representing equal energies de-

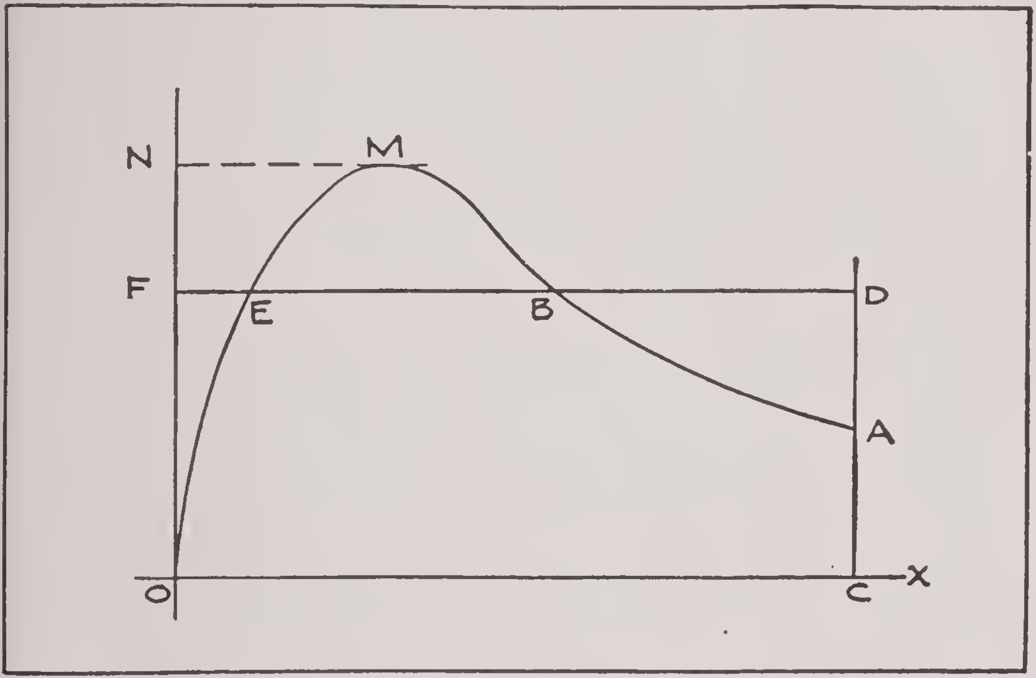


FIG. 4.

livered at the muzzle, the work areas must necessarily be equal. With the mean pressure a good idea can be had of the work performed by the powder in the gun by comparing the mean to the maximum pressure.

Assuming (Fig. 3) a quick powder, whose curve takes the shape OMA, the mean pressure will be drawn in such a way that the area $EMB = BDA$, neglecting OEF; the expression $\frac{OF}{ON}$ represents the ratio of the mean pressure to the maximum pressure.

Assuming (Fig. 4), on the other hand, a slow powder, whose pressure curve takes a more flattened shape, OMA, the ratio $\frac{OF}{ON}$

of the mean to the maximum pressure will be greater than the preceding one. It results from this that the ratio of the mean to the maximum pressure will give, by comparison, some information about the qualities of the powder used.

The mean pressure can easily be computed from the relation

$$\tfrac{1}{2}mV^2 = P_e \times A \times u,$$

$$P_e = \frac{wV^2}{2gAu}, \tag{6}$$

in which

m represents the mass of the projectile, in pounds $= \dfrac{W}{g}$.

V represents the initial velocity, in feet per second.

A represents the cross-section of the bore, in square inches.

u represents the travel of the projectile in the bore, in feet.

P_e represents the mean pressure, in pounds per square inch.

77. This gives now a clear understanding of the meaning of quick and slow powder. A scale of relative quickness can also be established, starting from the quickest, the powder of instantaneous combustion, in which $\dfrac{OF}{ON}$ is a minimum, and proceeding to the imaginary powder in which the maximum pressure is constant and, consequently, equal to the mean pressure. The ratio $\dfrac{OF}{ON}$ is also a factor for the selection of the powder most suitable for a gun in function of its elastic strength, because the slower the powder the greater the stress at the muzzle. In the naval guns the ratio $\dfrac{OF}{ON}$ varies from 0.47 to 0.7704.

78. To quote from a French authority: *

"These considerations explain the experimental results obtained when, in a given gun, increasing charges of slower powders are fired, maintaining such weights of charges as to keep a constant maximum pressure. The muzzle velocities increase at first until the successive increases become very small in proportion to the added weight of charge. The powder finally arrived at is 'the maximum powder,' at the given pressure, for the weight of projectile used.

* Maxime Crémieux, engineer in chief of naval artillery, "Naval Powders: Applied Interior Ballistics, 1914."

"The small final gains of velocity are due to the fact that the powder is not completely burned in the gun, which is too short in proportion to the slowness of the powder.

"Because of this small gain, the use of the maximum powder is not advantageous. It is all the less so, since the velocity tends to become irregular, the amount of powder not completely burned varying from one shot to another.

"If there are fired, at the constant maximum pressure, powders slower than this maximum powder, the velocities decrease, the fraction of powder unburned increasing. Grains of powder incompletely burned may be thrown from the muzzle of the gun. The irregularity of the velocity increases, and is shown by high variation of successive velocities from the mean. At the same time, and especially in the case of powders of irregular grain-shape, pressure gauges show irregular pressures, due to 'waves' of pressure.

"The problem of the determination of the most advantageous condition of loading consists in obtaining, with a given maximum pressure and weight of projectile, the maximum muzzle velocity compatible with a satisfactory regularity, indispensable to proper control of fire. The powder to employ is therefore that which immediately precedes 'the maximum powder.'"

79. In this analysis two important points have, for the sake of simplicity, been omitted.

In constructing the pressure curves, the curve has, in all save the curve for instantaneous combustion, been drawn through the origin, assuming zero pressure for zero travel of projectile and a small pressure for a minute travel thereof. In practice, however, the pressure must rise above the *"pressure of forcing"* before the projectile begins to move. This pressure of forcing is caused by the inertia of the projectile partly, but mainly by the resistance offered to its passage by the rifling band before it has been forced through the origin of rifling. This necessary pressure is from 3 to 5 tons per square inch.

80. The curve of pressures and its resultant work area represents only the work done on the projectile. The total energy of the powder, equivalent to weight times chemical potential heat energy per pound, is employed in (1) work upon the projectile as shown by the curve, (2) heating the projectile and the walls

of the chamber and bore, (3) minutely expanding the gun, (4) internal work in expanding the gases, (5) the recoil of the gun and other minor losses, such as rotation of projectile, forcing, friction, etc. Ingalls (revised 1911) states that 83 per cent of the energy of the powder is expended upon the motion of the projectile. Since the work is shown by the work area on the curve, we may expect that the pressure curve for all work done, and therefore for the actual pressure in the gun, should run higher than that drawn for the work done on the projectile alone. This is found to be the case, since the actual pressures as measured by gauges are 12 to 15 per cent higher than the curve.

81. To make use of the foregoing, it is necessary that formulas should be available to compute the approximate pressure curve of the powder. Based on the preceding fundamental principles, there have been deduced experimentally and mathematically semi-empirical ballistic formulas. The object of these is to determine the pressure of the gases at any point of the travel of the projectile, and the velocity thereof at that point.

Section III.—Historical.

82. Rodman's experiments and analyses, unfortunately cut short by the needs of the service at the beginning of the Civil War, were followed up more thoroughly in France than in the United States. With few exceptions, the French artillerists have conducted the most exhaustive researches into interior ballistics.

Emile Sarrau, engineer in chief of the French powder factories, was the first to derive, by exhaustive mathematical and experimental researches, formulas for the action in the gun of geometrically grained black powders. He considered the elements of granulation, density, and velocity of combustion of the grain—both in air and in the gun—and obtained working formulas which gave results confirmed almost exactly by experimental firings. Certain assumptions, necessarily not absolutely exact, were made to provide an initial point for mathematical analysis, and the constants employed in his formulas were so modified, after experimental firing, as to obviate the effect of these inexact assumptions. These assumptions were: (1) The gases expand adiabatically; this, of course, neglects heat expended in heating the walls of the chamber and bore of the gun; (2) the time required for the com-

plete inflammation of the charge is negligible as compared with the time of combustion.

Sarrau's formulas give expressions for the velocity and the pressure at any point of the travel of the projectile. They have been since accepted with slight modifications by all ballisticians as standard *for black powder*. At the time these researches were published in 1870 smokeless powder was, of course, undeveloped.

With the development and adoption of smokeless powders, it became apparent that the Sarrau formulas were not sufficiently accurate; in other words, did not fit the newer powders. This is not strange, when the great increase of time of combustion possible with smokeless powder is considered. With such an increase of time larger powder charges became practicable (without pressures unduly great), producing greater density of loading, more powder gases, greater energy, and higher muzzle velocity. By reason of such changes, the formulas of Sarrau, no longer accurate, have been to a large degree superseded, for smokeless powder use, by those of more recent investigators.

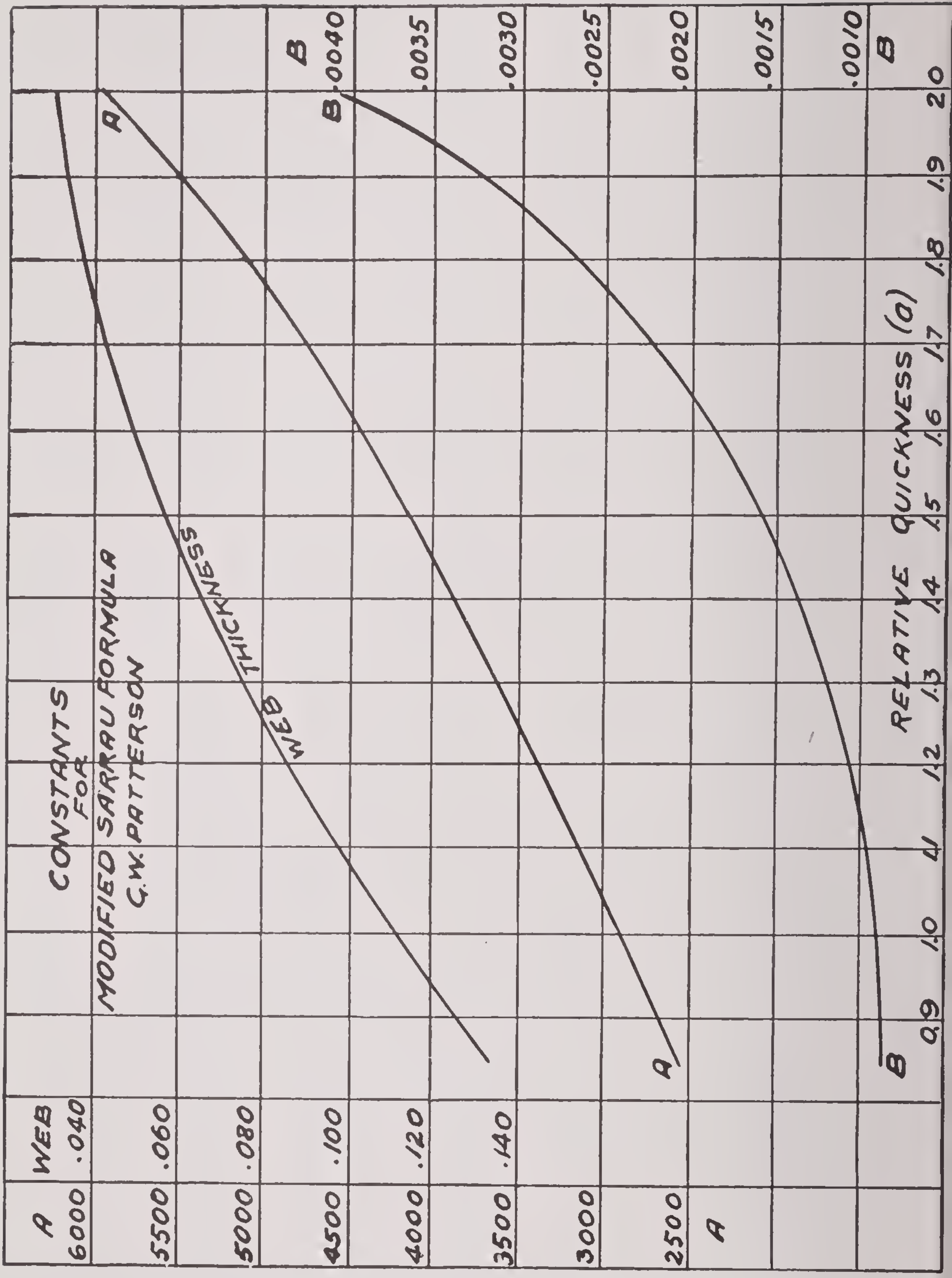
Among these may be mentioned Gossot, Liouville, Crémieux, Charbonnier, and Le Duc of France, Glennon and Ingalls of the United States, and Brynk of Russia. In general, the effort of these investigators, with the exception of Le Duc, has been so to modify the Sarrau analysis and resultant formulas as to render them applicable to smokeless powder.

The Le Duc formulas, originally derived from the results of experiments for calculation of recoil pressures, have given very satisfactory results at the Naval Proving Ground and have been adopted, by reason of their simplicity and accuracy, as the standard for naval use. These formulas are semiempirical, *i. e.*, partly derived from theory and partly from results of firing experiments.

The derivation and use of these Le Duc expressions are given in the following sections of this chapter. In passing, however, it is of interest to state briefly the Sarrau formula for velocity. With constants determined by G. W. Patterson at the Naval Proving Ground from the results of actual firing it is, in working form,

$$V = A\tilde{\omega}^{\frac{7}{16}} D(1 - BF).$$

A and B are constants determined from firing, and plotted on the curves shown in Fig. 5.


CONSTANTS FOR MODIFIED SARRAU FORMULA
G.W. PATTERSON
WEB THICKNESS
RELATIVE QUICKNESS (a)
A
6000
5500
5000
4500
4000
3500
3000
2500
WEB
.040
.060
.080
.100
.120
.140
B
.0040
.0035
.0030
.0025
.0020
.0015
.0010
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0

$\tilde{\omega}$ is the weight of powder charge.

$$D = \frac{u^{\frac{4}{10}}}{w^{\frac{1}{4}} S^{\frac{3}{8}} C^{\frac{1}{8}}},$$

$$F = \frac{(wu)^{\frac{1}{2}}}{C},$$

in which u is the travel of the projectile in the bore in feet.

w is the weight of the projectile in pounds.

S the capacity of the powder chamber in cubic inches.

C is the caliber of the gun in feet.

This formula gives accurate results in predicting smokeless powder charges for new types of guns or for new velocities in known guns.

The Sarrau formula for pressure is not considered adaptable or convenient for use with smokeless powders and will not be quoted.

For rough ballistic work the following relations are convenient and approximate:

(a) For mechanical powders $V = A\tilde{\omega}^{\frac{5}{8}}$.

(b) For chemical or smokeless powders $V = A\tilde{\omega}^{\frac{7}{10}}$.

The most complete treatise on the Sarrau formulas is found in "Researches on the Effects of Powder," by M. E. Sarrau, Proceedings of the United States Naval Institute, Volume X, No. 1.

Section IV.—Velocity and Pressure Formulas.

83. The point in work with velocities and pressures which is of most practical importance in firing the guns is the determination of the maximum pressure at any point in the bore, while for the design of new ordnance it is very important that the formulas should include practically all the elements of the gun in such form that, with some of them given, the rest may be determined. The Le Duc ballistic formulas have been found not only to give the best results, as finally adapted to our powder, but to be much the simplest to work with. These formulas and their derivation are given in the succeeding paragraphs.

84. The following symbols are used and are concentrated here for reference:

$\tilde{\omega}$, pounds weight of smokeless powder in the charge.

w, pounds weight of projectile.

Δ, density of loading, which varies between .4 and .7.

S, cubic inches capacity of powder chamber.

β, a powder constant, dependent on form and dimensions of grain, amount of volatiles, and temperature of powder. Largest for "slow" powders.

v, foot-seconds velocity at any point in the bore.

V, foot-seconds muzzle velocity. Also written I. V.

u, feet, travel of projectile in the bore to any point.

U, feet, total travel of projectile in bore from origin of rifling to muzzle.

A, square inches, cross-section of the bore.

g, foot-seconds, acceleration of gravity: 32.155 at Indian Head, Md.

δ, specific gravity of the powder. This varies between 1.54 and 1.62.

P, tons per square inch. Pressure on the base of the projectile at any point.

P_e, tons per square inch, mean effective pressure on base of projectile during entire travel through the bore.

$P_{(max)}$, tons per square inch. Maximum pressure on base of projectile producing velocity.

$P_{(max)(gauge)}$, tons per square inch. Maximum pressure in the bore, or maximum pressure gun must withstand.

$\left.\begin{matrix} a, \\ b, \end{matrix}\right\}$ constants depending on the powder, the gun, and density of loading.

85. In the development of the formulas, it was first assumed that the space velocity curve of the projectile in the bore is an hyperbola which is expressed by the equation

$$v = \frac{au}{b+u}. \tag{7}$$

86. Dividing both numerator and denominator of the right-hand member of (7) by u, we have

$$v = \frac{\frac{au}{u}}{\frac{b+u}{u}} = \frac{a}{\frac{b}{u}+1}.$$

If, now, u be infinite, we have

$$V = a.$$

That is, a is the value of v when u is infinite; or, in other words, it is the velocity the projectile would attain in a gun of infinite length, when the muzzle energy would represent all the work the powder charge was capable of doing, there being no energy lost or unexpended at the muzzle.

87. The useful work done by a unit quantity will be equal to the kinetic energy of the projectile as it leaves the muzzle at some velocity, v, *i. e.*, work done equals

$$\tfrac{1}{2}mv^2 = \tfrac{1}{2}\frac{w}{g}v^2.$$

If the gun be infinitely long, then as we found above, $v=a$, and this value, a, may be substituted for v in the expression for the kinetic energy of the projectile, and the expression will be $\frac{w \cdot a^2}{2g}$, and this is the measure of the total useful energy contained in unit weight of powder expanded to infinity. This multiplied by the weight of the charge of powder must be equal to the total energy of the projectile. Now let

p = pressure of unit weight of gas,
v = volume of unit weight of gas,
n = ratio of the specific heat at constant pressure to that at constant volume,

then we know, from Physics, $p \cdot v^n = k$ (constant).

The work done in expanding from v_1 to v_2 is

$$\int_{v_1}^{v_2} p\,dv.$$

Hence $$\text{Work}\Big]_{v_1}^{v_2} = \int_{v_1}^{v_2} p\,dv = k\int_{v_1}^{v_2}\frac{dv}{v^n} = \frac{k}{n-1}\left[\frac{1}{v_1^{n-1}} - \frac{1}{v_2^{n-1}}\right].$$

Then if $v_2 = \infty$

$$\text{Work}\Big]_{v_1}^{\infty} = \frac{k}{n-1} \times \frac{1}{v_1^{n-1}}.$$

We designate the work done by 1 pound of gas in expanding from the volume v_1, which it occupies at unit density, to infinity by E. Also the volume at unit density = 27.68 cubic inches (*i. e.*, the volume of 1 pound of water). Substituting this value of v_1 in the expression above, we have

$$E = \frac{k}{n-1} \times \frac{1}{(27.68)^{n-1}}.$$

88. If the expansion is from any other density than unity, say Δ, to infinity, then $v_1 = \frac{27.68}{\Delta}$ and the work done will be

$$\text{Work} = \frac{k}{n-1} \times \frac{\Delta^{n-1}}{(27.68)^{n-1}}. \qquad \text{(a)}$$

But

$$E = \frac{k}{n-1} \times \frac{1}{(27.68)^{n-1}}.$$

Hence (a) becomes $E\Delta^{n-1}$, which expresses the work done by unit weight of gas in expanding from some density, Δ, other than unity, to infinity.

This work, multiplied by the weight of the charge, $\tilde{\omega}$, must equal the energy of the projectile, $\frac{w \cdot a^2}{2g}$, so we have

$$\frac{w \cdot a^2}{2g} = \tilde{\omega} \times E\Delta^{n-1},$$

or

$$a^2 = 2gE\frac{\tilde{\omega}}{w}\Delta^{n-1},$$

whence

$$a = \sqrt{2gE}\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}} \Delta^{\frac{n-1}{2}}. \qquad \text{(b)}$$

89. Using the value of E found by experiment, the expression $\sqrt{2gE}$ reduces to the value 9706. But owing to losses through heating and expanding the gun, forcing pressure, friction, etc., our results will not check with the results of actual firings if we use this value. From long series of firings and tests we find the value of $\sqrt{2gE}$ for our work must be taken as 6823. This gives us an empirical value of a much less than the theoretical, but by using this value the calculated and actual results check very closely. The value of $\frac{n-1}{2}$ is found to be 1/12.

Substituting these values in equation (b), we get

$$a = 6823\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}} \Delta^{\frac{1}{12}}. \qquad (8)$$

90. *The constant b is twice the travel of the projectile to the point of maximum pressure.* Hence it depends first of all, as between different powders, on their relative quickness, or, with

any particular powder, upon the form and dimensions of the grain, *i. e.*, is proportional to β. It is also proportional to the initial air space. It is inversely proportional to some power of the chamber volume, and some power of the weight of the projectile, since increase in either of these decreases the distance to the point of maximum pressure. Given

S = chamber volume.
δ = density of powder.
Δ = density of loading.
w = weight of projectile.
β = powder constant.

Then, according to the logic of our relative proportions above,

$$b=\beta\times\frac{\text{initial air space}}{S^z\times w^y}. \qquad \text{(c)}$$

Now $\frac{S\Delta}{\delta}$ = space occupied by a charge of density δ loaded with a density of loading Δ in a chamber of capacity S. Therefore, $S-\frac{S\Delta}{\delta}$ = initial air space.

Hence equation (c) becomes

$$b=\beta\frac{S-\frac{S\Delta}{\delta}}{S^z\times w^y}=\beta\frac{S\left(1-\frac{\Delta}{\delta}\right)}{S^z\times w^y}.$$

Let

$$\frac{S}{S^z}=S^x.$$

Then

$$b=\beta\left(1-\frac{\Delta}{\delta}\right)\frac{S^x}{w^y}.$$

By experiment x and y have been determined to have the value $\frac{2}{3}$. Hence

$$b=\beta\left(1-\frac{\Delta}{\delta}\right)\left(\frac{S}{w}\right)^{\frac{2}{3}} \qquad (9)$$

91. To obtain the value of the *pressure* we differentiate the velocity equation, which gives the acceleration of the projectile. This multiplied by the mass of the projectile will give the *total pressure* on the base of the projectile producing velocity * ($f=ma$), which, divided by the cross-section area of the bore will

* Some of the pressure of the powder gases is used in rotating the shell.

give the pressure per unit area on the base of the shell producing velocity.

The process is as follows:

Differentiating equation (7),

$$\frac{dv}{dt}=\frac{ab}{(b+u)^2}\times\frac{du}{dt}=\frac{abv}{(b+u)^2}=\frac{a^2bu}{(b+u)^3}.$$

This is acceleration. The mass of the projectile is $\frac{w}{g}$, and A is the cross-section area of the bore. Hence

$$P=\frac{w}{g}\times\frac{1}{A}\times\frac{dv}{dt}=\frac{w}{gA}\times\frac{a^2bu}{(b+u)^3}.$$

Dividing by 2240 to get the value in tons, we have

$$P=\frac{wa^2bu}{2240gA(b+u)^3}. \tag{10}$$

92. This value of P is the pressure producing velocity exerted on the base of the projectile at any point, u, but owing to friction the force necessary to drive the rotating band through the rifling, heating, expanding the gun, etc., the pressure by gauge in the gun may be expected to be considerably higher. Such is, in fact, the truth, and it has been found that by multiplying the value of P from equation (10) by 1.12 it is brought to correspond very well with the values found by actual firing. That is,

$$P_{(max)}\times 1.12=P_{(max)(gauge)}. \tag{11}$$

Since P is a maximum when $u=b/2$ (see definition in paragraph 90), substituting this value for u in equation (10), we have

$$P_{(max)}=\frac{w}{2240gA}\times\frac{a^2b(b/2)}{(b+b/2)^3}=\frac{w}{2240gA}\times\frac{a^2b^2}{2}\times\frac{8}{27b^3},$$

or

$$P_{(max)}=\frac{4}{27}\times\frac{a^2w}{2240gAb}. \tag{12}$$

which expression gives the value of the maximum pressure on the base of the shell producing velocity.

93. We have no means of measuring the maximum pressure on the base of the projectile, but can very easily measure the maximum pressure in the bore of the gun by using pressure gauges. Consequently, equation (12) may be changed to a more con-

venient form for use by substituting for $P_{(max)}$ its equivalent $\frac{P_{(max)(gauge)}}{1.12}$ from equation (11), which will give

$$\frac{P_{(max)(gauge)}}{1.12} = \frac{4}{27} \times \frac{a^2 w}{2240gAb}.$$

Now clearing the expression for b, we have

$$b = \frac{4w}{27} \times \frac{1.12a^2}{2240gAP_{(max)(gauge)}}, \tag{13}$$

which gives a means of determining b by measuring the maximum pressure in the bore. But the expression is in terms of a, which is undesirable. To eliminate this we substitute in (13) the value of a found from equation (8), which gives

$$b = \frac{4w}{27} \times \frac{1.12\left[6823\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}}\Delta^{\frac{1}{12}}\right]^2}{2240gAP_{(max)(gauge)}}.$$

Now substituting for Δ its value from equation (1), *i. e.*, $\frac{27.68\tilde{\omega}}{S}$, we have

$$b = \frac{4w}{27} \times \frac{1.12 \times \overline{6823}^2 \times \frac{\tilde{\omega}}{w} \times \frac{\overline{27.68\tilde{\omega}}^{\frac{1}{6}}}{S^{\frac{1}{6}}}}{2240gAP_{(max)(gauge)}}$$

$$= \frac{4 \times 1.12 \times \overline{6823}^2 \times \overline{27.68}^{\frac{1}{6}} \times \tilde{\omega}^{\frac{7}{6}}}{27 \times 2240 \times 32.155 \times A \times S^{\frac{1}{6}} \times P_{(max)(gauge)}}. \tag{d}$$

For any given gun A and S are known, and, therefore, if we take

$$Q = \frac{4 \times 1.12 \times \overline{6823}^2 \times \overline{27.68}^{\frac{1}{6}}}{27 \times 2240 \times 32.155 \times A \times S^{\frac{1}{6}}}, \tag{14}$$

equation (d) may be written

$$b = \frac{Q\tilde{\omega}^{\frac{7}{6}}}{P_{(max)(gauge)}}. \tag{15}$$

94. This value, Q, is different for each gun, but is constant for all powders in any given gun. The values of Q for all guns in our service have been determined and tabulated. The values of Q are given below, together with the value of U, or total travel of projectile in the bore from origin to muzzle.

(NOTE.—Q is tabulated in terms of its logarithms and U is, of course, *in feet.*)

TABLE I.

Gun.	Mark.	Log Q.	U (total).
16-inch, 45	....	9.24345	51.821
14-inch, 50	IV	9.36818	50.250
14-inch, 45	I	9.38686	45.204
13-inch, 35	....	9.45155	31.211
13-inch, 35	I and II	9.45226	31.193
12-inch, 50	....	9.52310	42.165
12-inch, 45	V–5 and VI–3	9.52330	37.743
12-inch, 40	III–3	9.51251	32.751
12-inch, 35	I	9.53776	28.907
12-inch, 35	II	9.53776	28.851
10-inch, 30	I	9.73723	20.954
10-inch, 40	....	9.70761	27.302
8-inch, 35	....	9.98716	20.537
8-inch, 45	....	9.94946	24.971
7-inch, 45	....	0.09235	21.651
6-inch, 40	IV	0.30014	17.162
6-inch, 40	VII	0.30014	17.188
6-inch, 45	IX	0.30014	18.512
6-inch, 50	Arms. V	0.31411	22.312
6-inch, 50	VIII	0.26651	20.732
5-inch, 40	II and III	0.50802	13.982
5-inch, 50	V	0.46379	17.917
5-inch, 50	VI 3,000 f. s.	0.46488	17.917
5-inch, 51	VII and VIII	0.46530	17.929
4.7-inch	....	0.58832	17.173
4-inch, 40	....	0.75121	11.198
4-inch, 50	VII	0.70364	14.018
4-inch, 50	VIII	0.70364	14.018
4-inch, 50	IX	0.70364	14.018
3-inch, F. G.	....	1.16810	4.947
3-inch, L. G.	IV	1.13463	5.233
3-inch, 50	....	1.03594	10.658
6-pounder	....	1.38967	8.452
3-pounder	....	1.56387	6.560
1-pounder	....	1.89975	4.406

For gun-design work where A and S are variables it is convenient to use a different constant as follows:

$$Q_2 = \frac{186.53}{A \times S^{\frac{1}{6}}}.$$

95. In equation (10) for any specific case we know a and b, therefore the quantity $\dfrac{a^2bw}{2240gA}$ is a constant and for plotting a curve of pressures on the base of a *projectile* we substitute for this quantity the constant R_p, which is, of course, constant for the whole curve.

Equation (10) may then be written

$$P=\frac{R_p u}{(b+u)^3}, \tag{16}$$

which expresses the relation between the pressure on the base of the projectile at any point in the bore, and the travel, u, to that point.

This pressure will be a maximum when $u=b/2$, or

$$P_{(max)}=\frac{\frac{R_p b}{2}}{\left(\frac{3b}{2}\right)^3}=\frac{4R_p}{27b^2}.$$

From this

$$R_p=\frac{27b^2 P_{(max)}}{4}.$$

But $P_{(max)}$ is the maximum pressure on the base of the projectile producing velocity, which we cannot measure readily. Therefore, substituting for $P_{(max)}$ its equivalent, $\frac{P_{(max)(gauge)}}{1.12}$, from equation (11), which we can measure, we have

$$R_p=\frac{27b^2 P_{(max)(gauge)}}{4\times 1.12}. \tag{17}$$

96. This is still the value of R for a curve of pressures on the base of the projectile. But we desire to draw the curve of pressures acting on the gun in order to check the pressures on the gun against the corresponding strength of the gun that we may know whether or not the gun is safe, *i. e.*, whether or not the "powder fits the gun."

We know the pressure in the bore, *i. e.*, on the gun, will be 1.12 times the pressure on the projectile, or

$$P(\text{for gun})=P(\text{for projectile})\times 1.12.$$

But

$$P(\text{for projectile})=\frac{R_p u}{(b+u)^3}. \tag{16 bis}$$

Hence

$$P(\text{for gun})=\frac{R_p u}{(b+u)^3}\times 1.12=\frac{u}{(b+u)^3}\times R_p\times 1.12.$$

Call $R_p \times 1.12 = R_g$ and substituting the value of R_p from equation (17) we obtain

$$R_g = \frac{27b^2 P_{(max)(gauge)}}{4 \times 1.12} \times 1.12,$$

or

$$R_g = 6.75 b^2 P_{(max)(gauge)}. \qquad (18)$$

97. *The values of R found from* (17) *and* (18) *must not be confused.* The value found from (17) substituted in (16) will give a curve of pressures on the base of the projectile producing velocity, whereas the value of R from (18) substituted in (16), and values of P found for successive values of u, will give a curve of pressures on the gun down the bore of the gun. To distinguish these values of R we use the subscripts p and g as shown above.

98. A discussion of the derivation of the Le Duc formulas and constants is to be found in the Proceedings of the Naval Institute, No. 138. They were first determined by the French, and the constants originally used were those for French powders. The formulas came to notice in a series of articles in the *Revue d'Artillerie*, 1904, being there designated as Captain Le Duc's semi-empirical formulas. While approximately correct for us, they did not give entirely consistent results, and were corrected to their present values by experimental work at the proving ground, largely by firings in cut-off guns, of which four were obtained of the same caliber (5-inch), so that the velocities after different amounts of travel of the projectile were obtained. This work was planned, carried out, and deductions made by G. W. Patterson, powder expert. They may now be considered as standard, and, while of course subject to revision as more exact methods of determination of velocities and pressures are introduced, they have given excellent results. A marked example of this was the case of the 16-inch 45-caliber gun, whose powder charge and pressure were determined before the gun was built. The values, on actual firing, were found to be very nearly exact.

99. Fig. 6 shows the experimental battery used, and Fig. 7 shows longitudinal sections of the different guns in the battery.

The standard methods of determining velocity and pressure now in use at the proving ground are set forth in paragraph 792 *et seq.*

Fig. 6.

Section V.—Applications of the Formulas.

PROBLEMS.

100. *Formulas.*—For convenience the interior ballistic formulas most often used are grouped together.

$$\Delta=\frac{27.68\tilde{\omega}}{S}. \tag{1}$$

$$\delta=1.672-(.0178\times\text{T. V.})\ \text{(see Art. 44)}. \tag{2}$$

$$v=\frac{a\cdot u}{b+u}. \tag{7}$$

$$a=6823\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}}\Delta^{\frac{1}{12}}. \tag{8}$$

$$b=\beta\left(1-\frac{\Delta}{\delta}\right)\left(\frac{S}{w}\right)^{\frac{2}{3}}. \tag{9}$$

$$b=\frac{Q\times\tilde{\omega}^{\frac{7}{6}}}{P_{(max)(gauge)}}. \tag{15}$$

$$P=\frac{R\cdot u}{(b+u)^3}. \tag{16}$$

$$R_g=6.75b^2P_{(max)(gauge)}. \tag{18}$$

$$P_{(max)}=\frac{P_{(max)(gauge)}}{1.12}. \tag{11}$$

$$P_{(max)}=\frac{4a^2w}{27\times2240gAb}. \tag{12}$$

Is the powder suitable for the gun?—Interior ballistics finds its daily service use in answering this question, which, naturally, must be answered for each powder index manufactured. The firings at the proving ground give the data from which to calculate the powder pressure at every point along the bore. A curve of these bore pressures is drawn and superposed upon the strength curve of the gun. *If the ratio f, factor of safety, everywhere along the bore exceeds 1.4, the powder is considered suitable for the gun.* This work forms a large part of the daily routine at the Naval Proving Ground at Indian Head, Md.

101. For every lot of powder two pressure and two velocity curves must be drawn. To plot the first pressure curve a succession of charges of increasing weights are fired, and the bore pressures measured with pressure gauges. Points are plotted using the weights of charge as abscissæ, and the corresponding bore pressures as ordinates. Such a curve is shown in the lower right corner of the *facsimile* " Powder Test Sheet," Plate I.

From: Inspector of Ordnance in Charge.
To: Bureau of Ordnance.

NAVAL PROVING GROUNDS,
INDIAN HEAD, MD.,
October 25, 1915.

POWDER TEST SHEET.

Powder Test No. 2997.
Powder: {*Designation I. H. F. D. 9.* / *Index No. S. P. D. 1365.*}

Date.	Time.	Projectile. Make.	Year.	Lot.	Band. To base.	Width.	Diam.	Lip.	Weight.	Shape.	Powder. Heated. From °F.	Hours.	Charge.	Chamber pressure. Gauges. 1	2	3	4	5	6	Mean.	Muzzle velocity. Chronographs. A	B	C	Mean.
Oct. 19.	8.44	N. G. F.	....	....	1½	4	12,174	12.470	868	Slug	65	66	230	7.94	7.86	7 19	......	......	......	7.66	2130	2130	2130	2130
Do....	8.54	..do..	....	....	1½	4	12.173	12.478	870	do	65	66	330	16.20	16.84	16.84	16.44	16 68	16.76	16.63	2872	2872	2872	2872
Do...	9.05	..do...	....	....	1½	4	12.173	12.484	871.5	do.	65	66	344	18.89	19.08	18 71	18.08	18.71	17.99	18.58	2967	2967	2967	2967
Do....	9.16	..do...	....	....	1½	4	12.174	12.485	867.5	do.	65	66	322	15.30	15.59	15 73	15.14	15.66	15.66	15.51	2824	2824	2824	2824

Gun 12 in. 50 caliber.
Mark VII Mod. 1 No. 180—L.
Chamber 14611 cubic inches.
Rifling: Depth of grooves .075.
number of grooves 72.
pitch 1/50 to 1/32
Number of sections 4.
Ignition per section 300 grams C. P.
Previous rounds: {actual 52. / equivalent service 53.2.}
Erosion loss: {83 f. s. / 2.0 tons.}

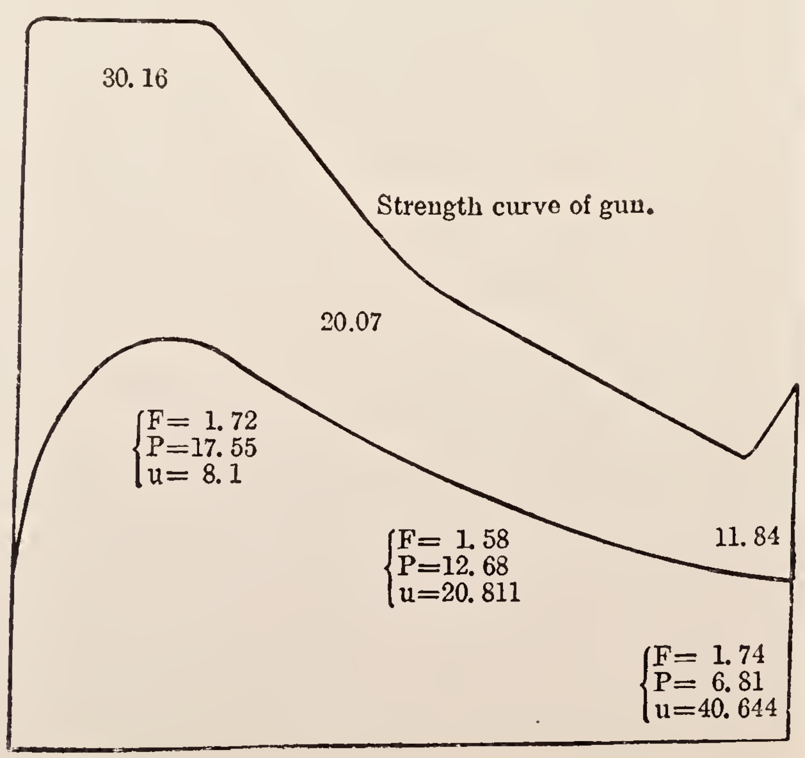
Weather: Fair. Temperature, F.: dry bulb 60.5; wet bulb 59.5.
Barometer 30.11 at 66° F. Wind 0 knots at o'clock (XII o'clock head wind.)

Cotton: Tennessee fiber.
Die: diameter...... .985
number of pins 7
pin diameter.. .072
Length of cut...... 1.75
Nitration 12.64%
Diphenylamine..... .45%

Dry grain: length....... 1.61
diameter.... .697
Diam. perforation....... .057
Average web............ .132
Outer web .... .128
No. grains per lb........30.6

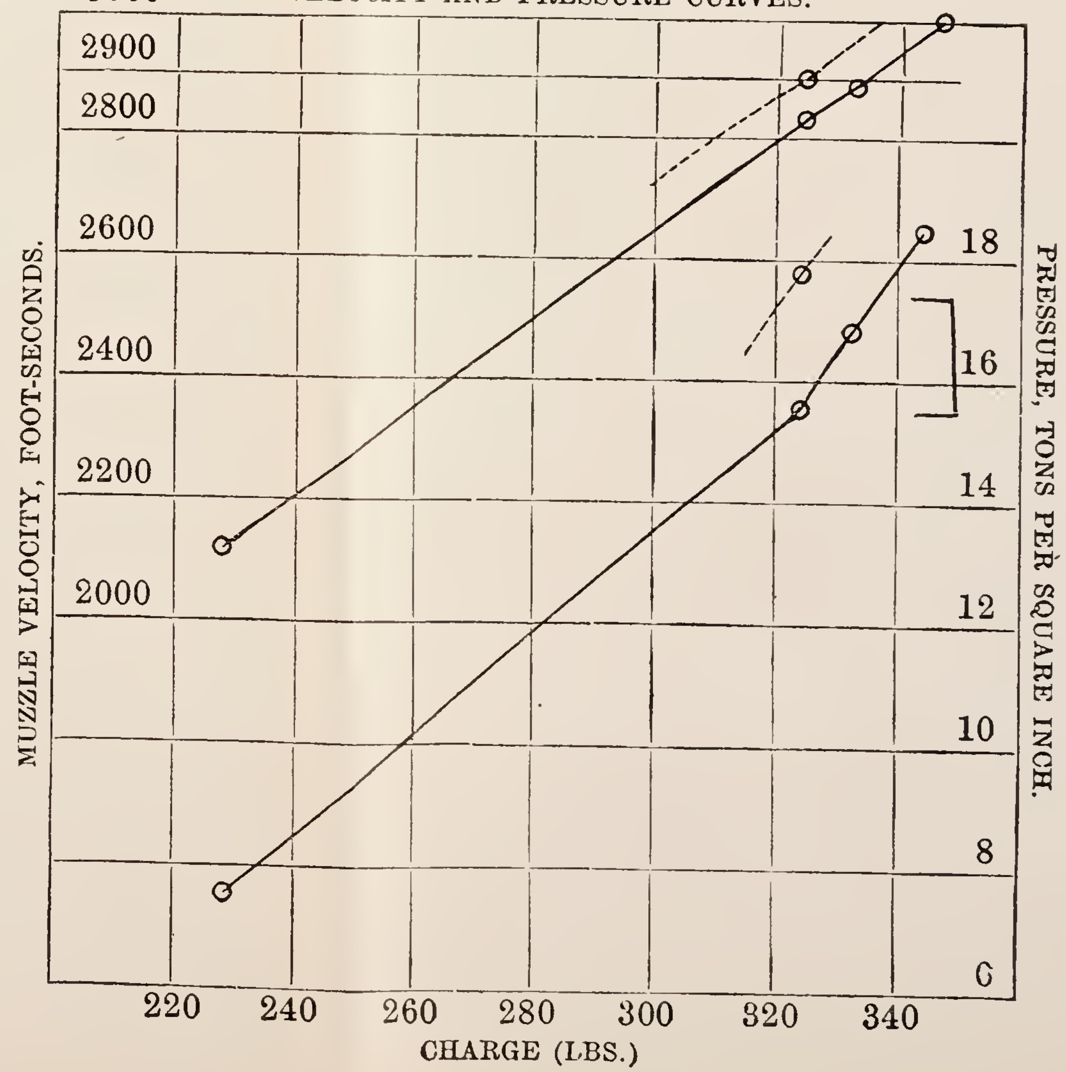
Time in dry-house: 116 days at 39.4° C.
66 days without heat.
German test, 135° C. {Violet 95′ / Explosion 5 hrs. +}
Surveillance test 65 .5 C. days.
Heat test of pyro 65°.5 C. 35 + minutes.
Total volatiles, W. P. method, {dry-house condition 6.73% / as received 7.00%}
Original firing test, {Date This date. / Record No:}
Lot contains 100,123 pounds.
Disposition: 100,123 pounds to Naval Mag., Lake Denmark, N. J.

Bureau Assignment.	P. G. ASSIGNMENT.
12″—50	Gun: 12″—50 cal.
Mk. VII.	
2,900 f. s.	Muzzle velocity: 2,900 f. s.
1,200 gms.	Ignition: 1,200 gms C. P.
(even lbs.) 323 lbs.	Charge: 322.5 lbs.
17.5 tons.	Pressure: 17.55 tons.



Curve of bore pressures.

VELOCITY AND PRESSURE CURVES.



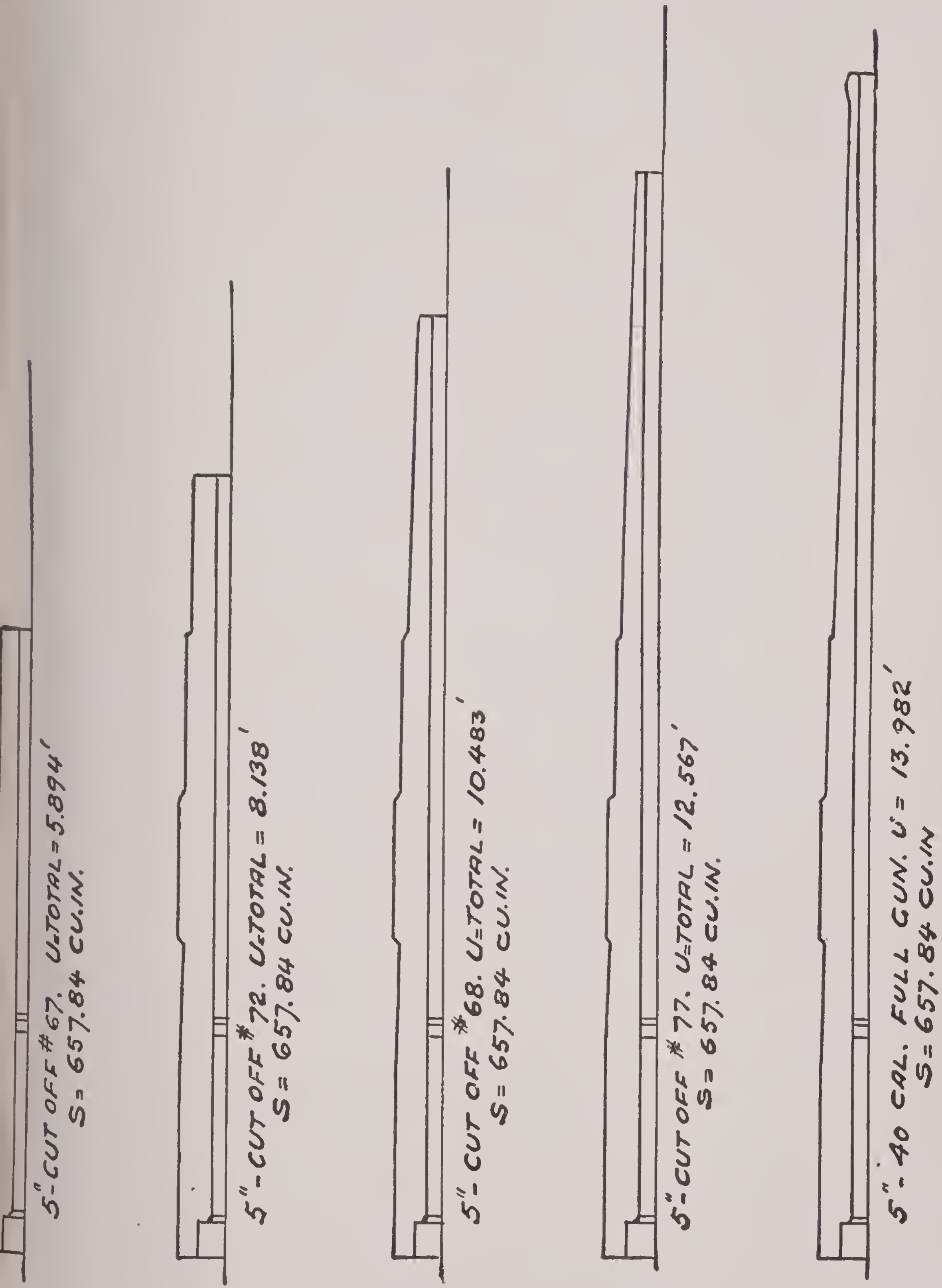

5"-CUT OFF #67. U-TOTAL = 5.894'
S = 657.84 CU.IN.
5"-CUT OFF *72. U-TOTAL = 8.138'
S = 657.84 CU.IN.
5"- CUT OFF *68. U=TOTAL = 10.483'
S = 657.84 CU.IN.
5"-CUT OFF * 77. U=TOTAL = 12.567'
S = 657.84 CU.IN.
5"- 40 CAL. FULL GUN. U = 13.982'
S = 657.84 CU.IN

FIG. 7.

102. To plot the first velocity curve, for each successive charge fired the resulting muzzle velocity (as well as bore pressure) is measured. Using the weights of charge as abscissæ and the corresponding velocities as ordinates, points are plotted and the curve is drawn through the points. An example of such a curve is shown on the " Powder Test Sheet," Plate I.

103. The firing of successive increasing weights of charges thus gives simultaneously the data to plot the first pressure and first velocity curves, and they are plotted together on the same cross-section sheet, the " weight of charge " scale being common to both curves.

104. After drawing these first pressure and velocity curves, and before assigning the service charge for any gun, the fact must be taken into consideration that the power is generally of necessity proved in guns that have been fired before and usually many times, while the charge to be assigned is one that in a new gun will give the desired muzzle velocity. Therefore the wear of the gun must be allowed for. The exact loss due to this wear has been determined from many actual firings, and has been tabulated.

In the case illustrated the tables showed that the loss due to erosion in the gun used was 83 foot-seconds velocity, and 2 tons in pressure. Therefore to get the curves as they would have been in a new gun the actual curves are *raised* by the necessary amount, and the dotted lines parallel to and above the actual curves obtained show the curves for a new gun. It is important to note that this decrease of pressure due to erosion is proportionally greater than the decrease in velocity, *i. e.,* erosion decreases pressures more, proportionally, than it does velocities. The bearing of this fact upon all powder tests can readily be appreciated.

105. In the example illustrated, for this particular gun the bureau has assigned a muzzle velocity of 2900 foot-seconds. (See " Powder Test Sheet," Plate I.) Therefore from the point where the 2900 foot-seconds line cuts the *corrected* velocity curve (*i. e.,* the curve for a new gun) we run down to the scale of charges, and find 322.5 pounds for the charge necessary for a new gun. (In this instance this weight checks very closely with the bureau's theoretical assignment of 323 pounds as given on the " Powder Test Sheet.")

Having picked, tentatively, this weight of charge, we now run up to the corrected pressure curve, and find that this weight of

charge should give a maximum bore pressure of 17.55 tons. This being within .05 tons of the bureau's assignment, it is safe to assume this charge will be satisfactory, and to proceed with the plotting of the second pressure and velocity curves.

106. The plotting of the second set of curves is done mathematically, and the work of the solution is as follows:

From equation (15) obtain b, taking log Q from Table 1.

$\tilde{\omega}=322.5$	log	2.50853
	$\frac{1}{6}$ log	0.41809
$P_{(max)(gauge)}=17.55$	colog	8.75572−10
Q (Table 1)	log	9.52310−10
$b=16.049$	log	21.20544−20

From equation (18) we obtain R_g.

6.75	log	0.82930
b ....log 1.20544......2	log	2.41088
17.55	log	1.24428
R_g	log	4.48446

107. In actual practice the omnimeter can be advantageously used in the solution of the remainder of the work, and at the proving ground it is generally used. In order to explain the solution more fully, and as an example of the method required in the Department of Ordnance and Gunnery, the solution by logarithms follows.

108. Take various points in the travel of the projectile and calculate the bore pressures at each of these points, computing also the factor of safety at each of the points as the work progresses. The strength of the gun at the points used is taken from the strength curve of the gun.

Note that the chamber must withstand the maximum bore pressure, no matter how far the projectile may have moved. In other words, so far as the chamber itself is concerned we need only know the gauge pressure. Also note that the maximum pressure does not occur when u is zero, for we use progressive powder. The maximum pressure is reached when the projectile has traveled to the point where $u=\frac{b}{2}$.

We see from the curve of gun strength on the "Powder Test Sheet" that the strength of the gun at the chamber is 30.16 tons,

and the maximum pressure in the gun (*i. e.*, the gauge pressure) is 17.55 tons, hence $f_1 = \frac{30.16}{17.55} = 1.72$. This is greater than 1.4, therefore strong enough.

Having found b above, we know the maximum pressure will occur when $u = \frac{b}{2}$ or at a point 8.02 feet from the start of the travel.

From equation (16) we have $P = \frac{R_g \cdot u}{(b+u)^3}$. For our illustration we will take only three points, *i. e.*, three values of u.

$u_1 = 8.1$ .... log 0.90849
$b + u_1 = 24.149$ .... log 1.38290
3 log 4.14870....colog 5.85130 − 10
R_g .... log 4.48446
$P_1 = 17.549$ .... log 11.24425 − 10

$$f_2 = \frac{30.16}{17.55} = 1.72 > 1.4 \text{ which is satisfactory.}$$

$u_2 = 20.811$ .... log 1.31829
$b + u_2 = 36.860$ .... log 1.56656
3 log 4.69968....colog 5.30032 − 10
R_g .... log 4.48446
$P_2 = 12.68$ .... log 10.10307 − 10

$$f_3 = \frac{20.07}{12.68} = 1.58 > 1.4 \text{ which is satisfactory.}$$

$u_3 = 40.644$ .... log 1.60917
$b + u_3 = 56.693$ .... log 1.75353
3 log 5.26059....colog 4.73941 − 10
R_g .... log 4.48446
$P_3 = 6.808$ .... log 10.83304 − 10

$$f_4 = \frac{11.84}{6.81} = 1.74 > 1.4 \text{ which is satisfactory.}$$

Now draw the curve of pressures and superpose it upon the curve of gun strength. A graphic representation of the relations between gun strength and bore pressures is thus obtained. (See lower left-hand corner of "Powder Test Sheet," Plate I.)

This is seen to be a very strong gun, and as the strength curve is regular it is only necessary to work out the few points as above

The pressure curve is now one that agrees with the gauges. Plot it upon the "Powder Test Sheet," and lay down the strength curve of the gun to the same scale. The factors of safety, f, are worked out at the various corners of the strength curve where the value changes. The test sheet therefore indicates at a glance the suitability of the powder. If the gun is unduly stressed at any point, the powder must be rejected for that gun.

Maximum pressure is thus seen to be not the whole consideration. It is possible for powders in some guns to be so "slow" that, while only a low pressure is obtained at the breech, the muzzle pressure would be sufficient to burst that part of the gun. This is readily appreciated if pressure curves for powders of various "quicknesses" are plotted. The muzzle velocity being fixed, the curve areas must all be the same, and decreasing the curve ordinate at one end of the gun can only result in raising the pressure at the other end.

Problem.—The proof of a 5-inch 50 Mk. V. gun at Indian Head gave as results: Velocity of 2700 foot-seconds, gauge pressure of 15 tons, charge of 19.2 pounds of powder, shell weighing 50 pounds. Determine the bore pressures at travels of 8, 22, and 40 calibers.

Ans. 14.96 tons; 9.7 tons; and 5.3 tons.

The strength curve shows at these points strengths of 20.8, 14.6, and 6.5 tons. What is the factor of safety at these points and is the powder suitable for the gun?

Ans. 1.39; 1.5; 1.2. The gun is too weak for this powder.

109. *To calculate reduced velocities.*—Due to certain circumstances it is often necessary to use only a part of the service charge. Thus it was, at the Dardanelles in 1915, necessary for the battleship *Queen Elizabeth* to use but three of the four sections of the charges for her 15-inch 45 guns in order to produce a good (large) angle of fall on shore, while at the same time reducing the wear on her guns. In order that she might fire accurately it became necessary for her officers to calculate the reduced velocity and then by exterior ballistics the proper sight-bar settings were obtained.

The method of procedure is as follows:

If the density of loading for the full charge is not known this must be found from equation (1). Call this Δ_f.

This Δ used in equation (8) will give the value a_f for the full charge.

In equation (7) we know the muzzle velocity for the full charge, and from Table 1 we obtain the value of u corresponding to the muzzle velocity (*i. e.*, the total u). These two values, together with the value of a found from (8), will give in equation (7) the value of b for the full charge (*i. e.*, b_f).

The values b_f and Δ_f, substituted in equation (9), in which we know all the other quantities but β, will give us the value of β.

β is constant for any given powder, being dependent on the form and dimensions of the grain, and does not vary, as do a and b, with the amount of the charge (*i. e.*, β is independent of the weight of charge, and consequent density of loading).

It must be noted that a change in the weight of charge produces a change in the density of loading. Therefore we must determine the density of loading for the reduced charge, Δ_r.

We now have a new value of Δ to use in equation (9), the other quantities in the right-hand member being the same as for the full charge. (β constant; same powder, only reduced in quantity, hence same δ; S and w being of course the same since the gun is not changed.) Therefore, using the reduced charge Δ (*i. e.*, Δ_r), we obtain a value of b for the reduced charge, b_r.

Also, using the reduced charge Δ in equation (8), we obtain a value of a for the reduced charge, a_r.

Using, now, the values of a_r and b_r (*i. e.*, reduced charge values), u being the same as for the full charge (*i. e.*, U for the same gun), we obtain a value of v for the reduced charge. As the value of u we should use should be the total travel, or U, the value of v resulting will be the muzzle velocity, or V.

As an example of the work the following problem is worked out in full.

Problem.—The firing of 38 pounds of a powder whose specific gravity is 1.58 in a 6-inch 50-caliber Mark 8 gun gives to a shell weighing 105 pounds a muzzle velocity of 2800 foot-seconds. The chamber capacity of the gun is 2050 cubic inches. Calculate the velocity that will be obtained when a charge of 30 pounds is used.

Solve equation (1) to obtain Δ (full).

$\tilde{\omega}=38$		log	1.57978
27.68		log	1.44217
$S=2050$	log 3.31175	colog	6.68825 − 10
$\Delta_f=0.5131$		log	19.71020 − 10

With this value of Δ solve equation (8) for a_f.

6823 .... log 3.83398
$\Delta_f =$ ......log 9.71020 − 10.......... $\frac{1}{12}$ log 9.97585 − 10
$\tilde{\omega}$ ....log 1.57977
$w = 105$ ....log 2.02119
$\tilde{\omega}/w$ ....log 19.55859 − 10..$\frac{1}{2}$ log 9.77929 − 10
$a_f = 3882.5$ .... log 23.58912 − 20

From (7) $v = \dfrac{a \cdot u}{b+u}$, or $b+u = \dfrac{a \cdot u}{v}$, whence $b = \dfrac{a \cdot u}{v} - u$.

$u = U = 20.732$ (Table 1).............. log 1.31664
a_f .... log 3.58912
$V = 2800$ ....log 344716......colog 6.55284 − 10
$\dfrac{a.u}{v} = 28.747$ .... log 11.45860 − 10
$u = 20.732$
$b_f = \ 8.015$

From equation (9) to find β.

$b_f = 8.015$ .... log 0.90391
$\left(1 - \dfrac{\Delta_f}{\delta}\right) = 1 - \dfrac{0.5131}{1.58} = 1 - .32 = 0.68$ ....colog 0.16749
$S = 2050$ .... log 3.31175
$w = 105$ .... log 2.02119
S/w .... log 1.29056
$\frac{2}{3}$ log 0.86037....colog 9.13963 − 10
β .... log 10.21103 − 10

From (1) we now find Δ for the reduced charge.

$\tilde{\omega} = 30$ .... log 1.47712
27.68 .... log 1.44217
$S = 2050$ ....colog 6.68825 − 10
$\Delta_r = 0.405$ .... log 19.60754 − 10

With new values of Δ and $\tilde{\omega}$ find a_r from (8).

6823 .... log 3.83398
$\Delta_r = 0.405$ .....log 9.60754 − 10...... $\frac{1}{12}$ log 9.967295 − 10
$\tilde{\omega} = 30$ .... log 1.47712
$w = 105$ ....colog 7.97881 − 10
$\tilde{\omega}/w$ .... log 19.45593 − 10..$\frac{1}{2}$ log 9.727965 − 10
a_r .... log 23.52924 − 20

With β constant and new value of Δ find new value of b from (9).

β .... log 0.21103

$1-\frac{\Delta_r}{\delta}=1-\frac{0.405}{1.58}=0.744$ .... log 9.87157 − 10

S/w (from above) .... $\frac{2}{3}$ log 0.86037

$b_r=8.7693$ .... log 10.94297 − 10

With values of a and b for the reduced charge find V from (7).

a_r .... log 3.52924

$u=U=20.732$ .... log 1.31664

$b_r+u=29.501$ ....log 1.46982....colog 8.53018 − 10

$V=2377.2$ .... log 13.37606 − 10

The muzzle velocity for the reduced charge will be 2377.2 f. s.

Having thus determined the velocity that will be obtained, it becomes necessary for the gunnery officer to determine what sight-bar range to use for the actual range at which the firing with the low charge is to be done. This is a problem in exterior ballistics, the solution of which will be found in "The Groundwork of Practical Naval Gunnery, or Exterior Ballistics."

110. To determine the charge for one gun, using powder designed for another, we first *assume* a density of loading, rather than a weight of charge. This is because the Department has set limits for the density of loading for each gun, and also because, by comparing the two calibers under consideration, we can arrive more quickly at an assumption, remembering that the powder of one caliber will always be relatively quicker in a gun of larger caliber, and vice versa.

After the weight of charge has been determined a number of pressures down the bore must be determined, and compared with the strength of the gun at the points, in order to know the factor of safety, and to be sure the powder fits the gun as well as possible.

Let the subscript 1 designate the values determined for the gun for which the powder was made, and the subscript 2 designate similar values determined for the gun in which we desire to use the powder.

If not already known, the value of Δ_1 is first found from equation (1), using $\tilde{\omega}_1$.

The value of a_1 is then found from (8), using $\tilde{\omega}_1$, w_1, and Δ_1.

Knowing V_1 and U_1, and using a_1, the value of b_1 is found from (7).

With b_1, Δ_1, S_1, w_1, and δ the value of β is found from (9).

A value of Δ_2 is now *assumed*, and with this the value of b_2 is found from (9), and $\tilde{\omega}_2$ from (1). (β and δ being the same as for the original gun, S_2 and w_2 being for the new gun.)

With Δ_2 and $\tilde{\omega}_2$ the value of a_2 is found from (8), and with a_2 and b_2 the value of $P_{(max)_2}$ is found from (12). This value in (11) gives the maximum working pressure in the gun, $P_{(max)(gauge)_2}$.

R_{g_2} is then found from (18), which with successive values of u in (16) gives a series of pressures down the bore. These pressures are compared with the strength of the gun (in which the powder is to be used) at the same points to be sure the charge is of the proper size.

If the assumed density of loading is not correct (*i. e.*, if the comparison of pressure and strength at the various points does not show the required factor of safety) a new value of Δ_2 must be assumed and the solution be repeated until a weight of charge is found that will fit the gun as well as possible.

To illustrate the procedure the following problem is solved:

Problem.—A charge of 90 pounds of a certain powder whose specific gravity is 1.56, fired in a 10-inch 30-caliber gun, having a chamber capacity of 6700 cubic inches, gives a projectile weighing 510 pounds an initial velocity of 2000 foot-seconds. What weight of this powder can be used in a 12-inch 50-caliber gun whose chamber capacity is 14,611 cubic inches, and whose shell weighs 870 pounds; the maximum allowable density of loading for this gun being 0.669, and the maximum allowable working pressure being 17.5 tons?

From equation (1).

27.68		log	1.44217
$\tilde{\omega}_1=90$		log	1.95424
$S_1=6700$	log 3.82607	colog	6.17393−10
$\Delta_1=0.3718$		log	9.57034−10

From equation (8).

6823		log 3.83398
$\bar{\omega}_1 = 90$	log 1.95424	
$w_1 = 510$	log 2.70757	
$\bar{\omega}_1/w_1$	log 9.24667 − 10 . . . $\frac{1}{2}$	log 9.62333 − 10
Δ_1	log 9.57034 − 10 . . $\frac{1}{12}$	log 9.96420 − 10
a_1		log 23.42151 − 20

From equation (7).

a_1		log 3.42151
$u_1 = 20.954$ (Table 1)		log 1.32126
$V_1 = 2000$	log 3.30103 . . . colog	6.69897 − 10
antilog 27.652		log 11.44174 − 10
$(-)\,U_1 = 20.954$		
$b_1 = 6.698$		

From equation (9).

$b_1 = 6.698$		log 0.82595
$\Delta_1 = 0.3718$	log 9.57034 − 10	
$\delta = 1.56$	log 0.19312	
$\Delta_1/\delta = 0.23835$	log 9.37722 − 10	
$1 - \Delta_1/\delta = 0.76165$	log 9.88176 − 10 . . . . colog	0.11824
$S_1 = 6700$	log 3.82607	
$w_1 = 510$	log 2.70757	
S_1/w_1	log 1.11850	
	$\frac{2}{3}$ log 0.74567 . . . . . colog	9.25433 − 10
$\beta = 1.579$		log 10.19852 − 10

A powder designed for a 10-inch gun will be relatively fast in a gun of larger caliber, such as a 12-inch, which is given in the problem. The maximum density of loading allowed by the Department is 0.669. If this density of loading is used the resultant pressure (max) is bound to be too great due to the quickness of the powder. As a first assumption, then, let us try a density of about half of the allowable, say 0.34.

From equation (9).

$\beta=1.579$			log	0.19852
$\Delta_2=0.34$	log	$9.53148-10$		
$\delta=1.56$	log	0.19312		
$\Delta_2/\delta=0.21795$	log	$9.33836-10$		
$1-\Delta_2/\delta=0.78205$			log	$9.89324-10$
$S_2=14611$	log	4.16468		
$w_2=870$	log	2.93952		
S_2/w_2	log	1.22516	$\frac{2}{3}$ log	0.81677
$b_2=8.101$			log	$10.90853-10$

From equation (1).

$S_2=14611$			log	4.16468
$\Delta_2=0.34$			log	$9.53848-10$
27.68	log	1.44217	colog	$8.55783-10$
$\tilde{\omega}=179.47$			log	$22.25399-20$

From equation (8).

6823			log	3.83398
$\tilde{\omega}_2=179.47$	log	2.25399		
$w_2=870$	log	2.93952		
$\tilde{\omega}_2/w_2$	log	$9.31447-10$	$\frac{1}{2}$ log	$9.65723-10$
$\Delta_2=0.34$	log	$9.53148-10$	$\frac{1}{12}$ log	$9.96096-10$
a_2			log	$23.45217-20$

From equation (12).

a_2	log	3.45217	2 log	6.90434
4			log	0.60206
$w_2=870$			log	2.93952
27	log	1.43136	colog	$8.56864-10$
2240	log	3.35025	colog	$6.64975-10$
$g=32.155$	log	1.50725	colog	$8.49275-10$
$A=\pi\cdot r^2$ 3.1416	log	0.49715	colog	$9.50285-10$
$r^2=36$	log	1.55630	colog	$8.44370-10$
b_2	log	0.90853	colog	$9.09147-10$
$P_{(max)2}$			log	$61.19508-60$

From equation (11).

$P_{(max)2}$			log	1.19508
1.12			log	0.04922
$P_{(max)(gauge)2}$ 17.55			log	1.24430

This value of the maximum working pressure, 17.55, is almost exactly equal to the limit of pressure laid down for the gun, hence the assumed value of the density of loading is satisfactory. Therefore any charge of this powder not exceeding 179 pounds will not produce an excessive maximum pressure. Had the value of the maximum pressure been too great another assumption of Δ_2 would have been required, and the work repeated. Had the pressure been much below that allowed, and a greater pressure been desired, the work would have been repeated in the same manner as above, using a greater value of Δ_2.

The work above has given a weight of charge that will not produce an excessive maximum pressure. It now remains to check up the pressures along the bore. (In this particular case it is evident that as the maximum pressure is safe all the others will be also, and no further work is necessary. This is not always the way of the matter.)

The further work, then, is to calculate a series of pressures, compare these pressures with the corresponding strengths of the gun, and obtain the values of the "factors of safety." The procedure is exactly like that shown above in Art. 108.

111. Velocity given by same powder in guns of different caliber.

Once the limiting density of loading, and consequent maximum weight of powder charge, has been determined for a gun other than that for which it was designed, the problem is to find the velocity any charge of this powder (equal to or less than the maximum allowable) will give in the gun in which it is desired to be used.

The first part of this solution is exactly like the first part of the solution for the maximum weight of charge allowable to use. To show clearly the whole procedure that solution will not be considered here, but the whole problem will be solved.

As before, let the subscript 1 denote values for the gun for which the powder was designed, and the subscript 2 the values for the gun in which the powder is to be used.

From equation (1) the value of Δ_1 is found. Using this value with $\tilde{\omega}_1$, and w_1 in (8) gives a_1, which used with the values for gun 1 in (7) will give b_1. This b_1, with the other values necessary for gun 1 in (9), will give β.

β is, of course, the same for both guns.

With the charge of powder decided upon (not greater than the maximum allowable), and using S_2, the value of Δ_2 is found from (1). With Δ_2, and the other necessary values for gun 2, the values of a_2 and b_2 are determined from (8) and (9), respectively. With a_2, b_2, and U_2 the value of V_2 is found from (7), which is the quantity whose value is desired.

As an example of the work the following problem is solved:

Problem.—A charge of 90 pounds of a certain powder whose specific gravity is 1.56, fired in a 10-inch 30-caliber gun, whose chamber capacity is 6700 cubic inches, gives an initial velocity of 2000 foot-seconds to a shell weighing 510 pounds. If 175 pounds of this powder is fired in a 12-inch 50-caliber gun whose chamber capacity is 14,600 cubic inches, what velocity will be given a shell weighing 870 pounds?

From equation (1).

27.68		log 1.44217
$\tilde{\omega}_1 = 90$		log 1.95424
$S_1 = 6700.$	log 3.82607	colog 6.17393 − 10
$\Delta_1 = 0.3718$		log 9.57034 − 10

From equation (8).

6823		log 3.83398
$\tilde{\omega}_1 = 90$	log 1.95424	
$w_1 = 510$	log 2.70757	
$\tilde{\omega}_1 / w_1$	log 9.24667 − 10 . . $\frac{1}{2}$	log 9.62333 − 10
Δ_1	log 9.57034 − 10 . . $\frac{1}{12}$	log 9.96419 − 10
$a_1 = 2639.4$		log 23.42150 − 20

From equation (7). $b = \frac{a \cdot U}{V} - U.$

a_1		log 3.42150
$U_1 = 20.954$ (Table 1)		log 1.32126
$V_1 = 2000$	log 3.30103	colog 6.69897 − 10
antilog = 27.652		log 11.44173 − 10
$(-) U_1 = 20.954$		
$b_1 = 6.698$		

From equation (9).

$b_1=6.698$		log 0.82595
$\Delta_1=0.3718$	log 9.57031 − 10	
$\delta=1.56$	log 0.19312	
$\Delta_1/\delta=0.23834$	log 9.37719 − 10	
$1-\Delta_1/\delta=0.76166$	log 9.88176 − 10	colog 0.11824
$S_1=6700$	log 3.82607	
$w_1=510$	log 2.70757	
S_1/w_1	log 1.11850	
	$\frac{2}{3}$ log 0.74567	colog 9.25433 − 10
$\beta=1.579$		log 10.19852 − 10

From equation (1).

27.68		log 1.44217
$\tilde{\omega}_2=175$		log 2.24304
$S_2=14600$	log 4.16435	colog 5.83565 − 10
$\Delta_2=0.3318$		log 9.52086 − 10

From equation (8).

6823		log 3.83398
$\tilde{\omega}_2=175$	log 2.24304	
$w_2=870$	log 2.93952	
$\tilde{\omega}_2/w_2$	log 9.30352 − 10	$\frac{1}{2}$ log 9.65176 − 10
$\Delta_2=0.3318$	log 9.52086 − 10	$\frac{1}{12}$ log 9.96007 − 10
$a_2=2791.3$		log 23.44581 − 20

From equation (9).

$\beta=1.579$		log 0.19852
$\Delta_2=0.3318$	log 9.52086 − 10	
$\delta=1.56$	log 0.19312	
$\Delta_2/\delta=0.21268$	log 9.32774 − 10	
$1-\Delta_2/\delta=0.78732$		log 9.89615 − 10
$S_2=14600$	log 4.16435	
$w_2=870$	log 2.93952	
S_2/w_2	log 1.22483	$\frac{2}{3}$ log 0.81655
$b_2=8.1511$		log 10.91122 − 10

From equation (7).

$a_2 = 2791.3$		log	3.44581
$U_2 = 42.165$ (Table 1)		log	1.62495
$b_2 = 8.151$			
$b + U = 50.316$	log 1.70170	colog	8.29830 − 10
$V_2 = 2339.2$		log	13.36906 − 10

The value V_2 is, then, the velocity that will be given by the powder from gun 1 when used in gun 2. The sight-bar setting to use to hit at any desired range is a problem whose solution lies in the field of exterior ballistics.

112. Problem on gun design.—Certain requirements that a new gun must fulfil are laid down before any work on the design is commenced, these requirements being taken from a consideration of the dimensions of guns already built.

Suppose a new 12-inch 50 gun is to be designed. The following approximate requirements will be laid down:

Shell = 870 lbs. Max. working pressure = 17 tons.

I. V. = 2900 f. s. Δ to be not greater than .65. δ = about 1.55.

Chambrage = 1.25. Length of chamber to be from 6 to 7 times its diameter.

Then the problem that must be solved before the design can be even roughly sketched is to determine—

a. The weight of charge, $\tilde{\omega}$.

b. The capacity of the powder chamber, S.

c. Approximate dimensions of the powder chamber.

d. The characteristic of the powder, β.

e. At least five points of pressure and velocity curve, and construct the approximate curves.

(a) Before the logarithmic and arithmetical work can be started certain new equations must be derived from those already deduced. This work is as follows:

Dividing both numerator and denominator of the right-hand side of equation (7) by b there results

$$V = \frac{\frac{a \cdot u}{b}}{1 + \frac{u}{b}}.$$

A new symbol is here introduced, *i. e.*, $M = \frac{U}{b}$, hence

$$V = \frac{a \cdot M}{1 + M},$$

or

$$a = \frac{(1 + M) \cdot V}{M}. \tag{A}$$

(b) From the assumption of the value of M it follows that $b = \frac{U}{M}$, and substituting this value of b in equation (12) it follows that

$$P_{(max)} = \frac{4 \times a^2 \times w \times M}{27 \times 2240 \times g \times A \times U},$$

whence

$$a = \sqrt{\frac{27 \times 2240 \times g \times A \times U \times P_{(max)}}{4 \times w \times M}}. \tag{B}$$

Equation (B) may be written

$$a = \sqrt{\frac{K}{M}} \tag{C}$$

where K is taken equal to all the quantities in equation (B) that are constant for any given gun.

That is,

$$K = \frac{27 \cdot 2240 \cdot g \cdot A \cdot U \cdot P_{(max)}}{4 \cdot w}. \tag{19}$$

Equating equations (A) and (C) gives

$$\sqrt{\frac{K}{M}} = \frac{V}{M}(1 + M),$$

or

$$K \cdot M = V^2(1 + 2M + M^2);$$

$$M^2 + 2M + 1 - \frac{K \cdot M}{V^2} = 0,$$

$$M^2 + \left(2 - \frac{K}{v^2}\right)M + 1 = 0,$$

which quadratic being solved

$$M = \frac{-\left(2 - \frac{K}{v^2}\right) \pm \sqrt{\left(2 - \frac{K}{v^2}\right)^2 - 4}}{2}. \tag{20}$$

(c) In solving logarithmically the two factors in the numerator of (20) are solved separately, or

$$x=\left(2-\frac{K}{v^2}\right), \qquad \text{and} \qquad y=\sqrt{\left(2-\frac{K}{v^2}\right)^2-4},$$

whence

$$M=\frac{-x+y}{2}. \tag{20a}$$

(d) Equation (8) gives a value of a which we may equate to equation (A), whence

$$a=6823\cdot\Delta^{\frac{1}{12}}\cdot\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}}=\frac{V}{M}(1+M)=a,$$

or

$$V=6823\cdot\Delta^{\frac{1}{12}}\cdot\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}}\cdot\left(\frac{M}{M+1}\right).$$

Whence

$$\left(\frac{\tilde{\omega}}{w}\right)^{\frac{1}{2}}=\frac{V(M+1)}{6823\cdot\Delta^{\frac{1}{12}}\cdot M},$$

or

$$\tilde{\omega}=\left[\frac{V(M+1)}{6823\cdot\Delta^{\frac{1}{12}}\cdot M}\right]^2\times w. \tag{21}$$

(e) The logarithmic work follows.

Solution.—The diameter of the powder chamber may be, by the conditions, $=1.25\times 12$, or $=15$ inches, and as a point to start from this diameter is used. It is not the final diameter.

The length of the powder chamber will be between 15×6, or 90 inches, and 15×7, or 105 inches.

Take 93 inches as a first trial length. The total length of the gun take as 600 inches. The total travel of the projectile, U, is then 600 minus 93 or 507 inches, which is 42.25 feet.

$P_{(max)(gauge)}$ has been given as 17 tons, hence, from equation (11), $P_{(max)}$ is 15.18 tons.

From equation (19) find K.

27		log	1.43136
2240		log	3.35025
$g=32.155$ (at proving ground)		log	1.50725
$A=(3.1416\times 36)$ 3.1416		log	0.49715
36 sq. in.		log	1.55630
$U=42.25$ ft.		log	1.62583
$P_{(max)}=15.18$		log	1.18127
4	log 0.60206	colog	9.39794 − 10
$w=870$	log 2.93952	colog	7.06048 − 10
K		log	27.60783 − 20

From equation (20a).

K		log	7.60783
V (specified) = 2900 f. s. . . log 3.46240			
	2 log 6.92480 . .	colog	3.07520 − 10
$\dfrac{K}{v^2} = 4.8198$		log	10.68303 − 10
$x = 2 - \dfrac{K}{v^2} = -2.8198$ . . . . log(−)0.45022			
$\left(2 - \dfrac{K}{v^2}\right)^2 = 7.9513$ . . . . 2 log 0.90044			
minus 4.0000			
3.9514 . . . . log 0.59675			
$y = 1.9878$ . . . . $\frac{1}{2}$ log 0.29838			
$y - x = 4.8076$			
$\frac{1}{2}(y - x) = 2.4038 = M$			
$M + 1 = 3.4038$			

From equation (21).

$V = 2900$ f. s.		log	3.46240
$M + 1 = 3.4038$		log	0.53196
6823 . . . . log 3.83398	. . . . .	colog	6.16602 − 10
Δ (specified) 0.65 . . . . log 9.81291 − 10			
	$\frac{1}{12}$ log 9.98441 − 10 . .	colog	0.01559
$M = 2.4038$ . . . . log 0.38089	. . . . .	colog	9.61911 − 10
		log	9.79508 − 10
		2 log	19.59016 − 20
$w = 870$		log	2.93952
$\tilde{\omega} = 338.5$ lbs.		log	22.52968 − 20

From equation (1).

27.68		log	1.44217
$\tilde{\omega} = 338.5$		log	2.52968
$\Delta = 0.65$ . . . . lig 9.81291 − 10 . .		colog	0.18709
$S = 14{,}419$ cu. in.		log	4.15894

The assumed diameter was taken as 15 inches, and from this a length of 93 inches was found for the length of the powder chamber. Keeping this length of chamber fixed, the true diameter of the chamber is found.

$$\text{Space} = \text{Area} \times \text{Length} = \frac{\pi \cdot D^2}{4} \times 93,$$

or

$$D = \sqrt{\frac{4 \cdot S}{93 \cdot \pi}}.$$

4		log 0.60206
$S = 14419$		log 4.15894
93	log 1.96848	colog 8.03152 − 10
3.1416	log 0.49715	colog 9.50285 − 10
		log 22.29537 − 20
$D = 14$		½ log 1.14769

That is, the proper diameter of the chamber, for a chamber length of 93 inches, to give a density of loading of 0.65 with a charge of 338.5 pounds of powder is 14 inches. Hence the *approximate dimensions* of the chamber are 93 by 14 inches.

These dimensions may be changed as the work on the design of the gun progresses. Some other value of the density of powder or loading, or for structural reasons, the dimensions may require change.

Any change will require new values of K, M, etc., to be found, *i. e.*, a new solution from the beginning.

The "chambrage" being the ratio of the diameter of the chamber to the diameter of the bore gives $\frac{14}{12} = 1.166$, which, being less than 1.25 as specified, is satisfactory.

The next step is to determine β from equation (9), having $b = \frac{U}{M}$.

$U = 42.25$		log 1.62583
$M = 2.4038$	log 0.38089	colog 9.61911 − 10
$\Delta = 0.65$	log 9.81291 − 10	
$\delta = 1.55$ (specified)	log 0.19033	
$\Delta/\delta = 0.41935$	log 9.62258 − 10	
$1 - \Delta/\delta = 0.58065$	log 9.76392 − 10	colog 0.23608
$S = 14419$	log 4.15899	
$w = 870$	log 2.93952	
S/w	log 1.21942	
	⅔ log 0.81295	colog 9.18705 − 10
$\beta = 4.6566$		log 20.66807 − 20

(f) Having secured the foregoing results and seeing that they are within reason, the gun can be laid out along these lines. Then the gun may be altered in various dimensions for various reasons. If this is done, new calculations must be made.

To construct the pressure and velocity curves, U as determined was 42.25 feet. Select five points to use. Take, 3, 8, 15, 24, and 36 feet. Since $M=2.4038=\frac{U}{b}$, $b=17.6$,

$$a=\frac{2900}{M}(M+1)=\frac{2900\times 3.4038}{2.4038}=4106.5. \qquad \text{(A } bis\text{)}$$

Using $v=\frac{au}{b+u}$, the velocity curve is calculated.

$u_1=3$	$u_2=8$	$u_3=15$	$u_4=24$	$u_5=36$
$b+u_1=20.6$	$b+u_2=25.6$	$b+u_3=32.6$	$b+u_4=41.6$	$b+u=53.6$
log= 1.31387	log= 1.40824	log= 1.51322	log= 1.61909	log= 1.72916
colog 8.68613	8.59176	8.48678	8.38091	8.27084
a log 3.61347	3.61347	3.61347	3.61347	3.61347
u log .47712	.90309	1.17609	1.38021	1.55630
2.77672	3.10832	3.27634	3.37459	3.44061
$v_1=598$ f. s.	$v_2=1283$ f. s	$v_3=1889$ f. s.	$v_4=2369$ f. s.	$v_5=2758$ f. s.

With these points the velocity curve may be drawn.

The next step is to determine the pressures at these points.

From equation (18).

6.75	....	log 0.82930
$b=17.6$	...........log 1.24551......2	log 2.49102
$P_{(max)(gauge)}=17$	....	log 1.23045
R_g	....	log 4.55077

From equation (16), using the same progressive values of u,

$u_1=3$	$u_2=8$	$u_3=15$	$u_4=24$	$u_5=36$
$b+u=20.6$	$b+u=25.6$	$b+u=32.6$	$b+u=41.6$	$b+u=53.6$
log 1.31387	log 1.40824	log 1.51322	log 1.61909	log 1.72719
3 log 3.94161	3 log 4.22472	3 log 4.53966	3 log 4.85727	3 log 5.18748
colog 6.05839	colog 5.77528	colog 5.46034	colog 5.14273	colog 4.81252
R log 4.55077	R log 4.55077	R log 4.55077	R log 4.55077	R log 4.55079
u log 0.47712	u log 0.90309	u log 1.17609	u log 1.38021	u log 1.55630
log 1.08628	log 1.22914	log 1.18720	log 1.07371	log 0.91959
$P_1=12.198$	$P_2=16.949$	$P_3=15.389$	$P_4=11.85$	$P_5=8.31$

(g) Multiply the pressures by 1.4 and the values of the ordinates for the minimum "strength curve" are obtained.

Thus the three curves necessary before the finished design of the gun is adopted are found.

A complete sketch, showing the gun and the curves therefor, is given for the 5-inch 50 gun, with muzzle velocity of 2300 foot-seconds, in Plate II.

Plate III shows the curves for M. V. 2700 foot-seconds for this gun. It is evident that the curves of pressure lie too close to the curve of gun strength and the factor of safety is too low. At $u=7$, the factor is found to be 1.12; at $u=32$, 1.23; and at $u=41$, 1.26. The factor of safety is too small at the breech, at the chase, and at the muzzle; consequently the powder is not suitable to the gun; or, more exactly, the gun is not suitable for such a velocity, because neither change in the charge nor in the characteristic of the powder could bring the factor of safety to the proper figure throughout. A smaller charge of a quicker powder would lower the pressure at the muzzle and increase the factor of safety at that point, but at the same time would raise the pressure at the breech and reduce there the factor, which is already too small. A large charge of a slower powder would reduce the pressure at the breech but would increase it at the muzzle; hence the gun is really not suitable for such a velocity. The standard velocity for this gun is 2300 foot-seconds, with resulting curves as shown in Plate II.

113. To determine the proper dimensions for a new powder. Considerable time, some three months, is required after the manufacture of a powder is commenced before an index of it is completed and ready for firing tests and issuance to the service. The powder must, therefore, be made on fairly accurate assumptions in order that it may suit the new type or caliber of gun in which it is to be used.

For example, it was necessary to determine what web should be used for the 16-inch 45 and the 14-inch 45 and 14-inch 50 guns, guns larger than any previously manufactured.

This work is done by powder experts, and no set rules can be laid down for the determination of β, and the "web thickness."

In general, however, the procedure is as follows:

By means of equations (7), (8), and (9) values of β are determined for known and satisfactory powders actually in use in all different calibers of guns.

That is, a is found from (8), then b is found from (7), and then β is found from (9).

The web thickness of each powder is also measured, and a curve is then plotted using the web thickness of the powder as abscissa, and the value of β for that powder as ordinate. In this way a great number of points are plotted, and through the points a fair curve is drawn. This is known as the "β curve."

By extending the curve, its form having been determined from known powders, values of β and corresponding "web thicknesses" for larger and unknown powders are found.

It remains, then, to determine the proper value of β to use, for, knowing the value of β, the corresponding "web thickness" can be picked from the curve.

From the results of previous experience, and firings in many types of guns, a maximum desirable density of loading is laid down by the Navy Department. With this value of Δ the maximum weight of charge is determined from equation (1).

Using a value of β from the "β curve," and the maximum density of loading, a value of b is found from (9). This b and the $\tilde{\omega}$ corresponding to the maximum density of loading give a value of $P_{(max)(gauge)}$ in (15).

Values of $\tilde{\omega}$ decreasing in increments of 5 pounds from the maximum are taken, and the corresponding values of Δ, b, and $P_{(max)(gauge)}$ deduced from equations (1), (9), and (15) (β remaining constant).

The resultant pressures from (15) are plotted as ordinates against the corresponding charges as abscissæ, and the curve resulting from the points is known as the "Le Duc pressure curve."

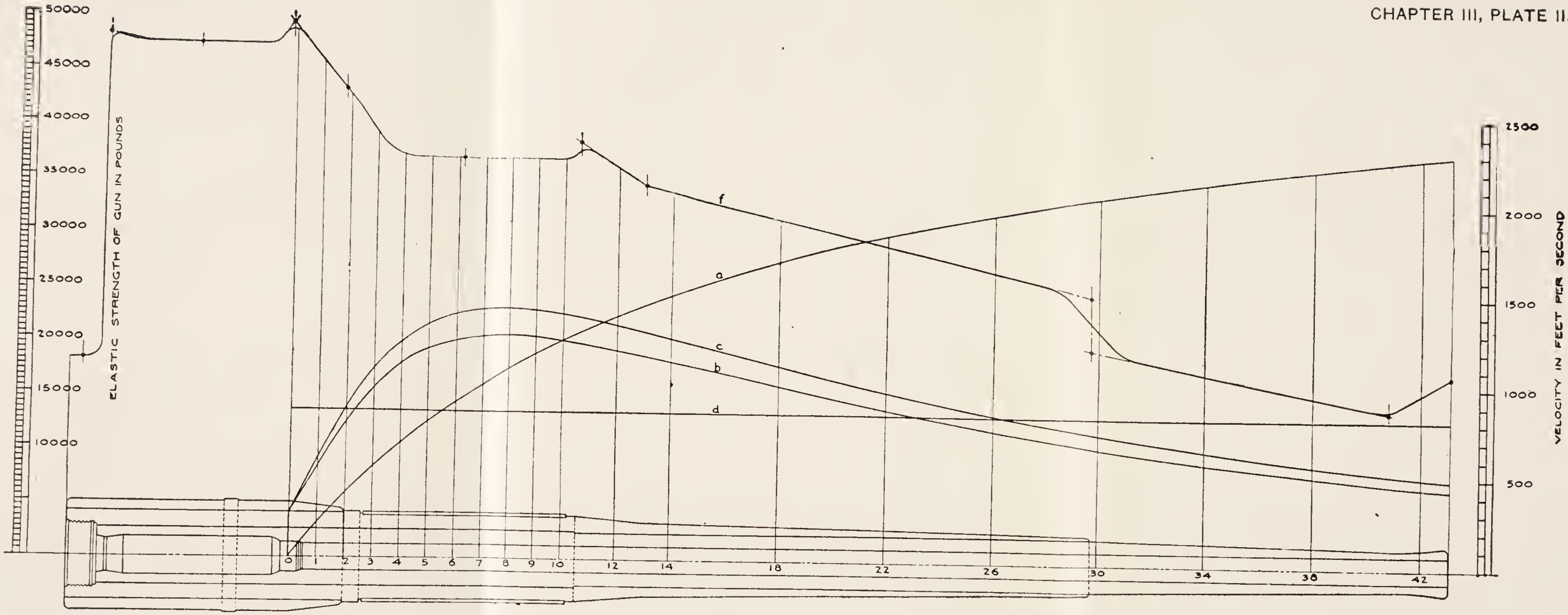
Powders are then plotted on this curve, and if the points fall below the curve, it being a maximum curve, they are good powders. Those plotting above the curve are rejected.

The final determination of "web thickness" is reached by assuming values of β and $\tilde{\omega}$, and plotting points on the "Le Duc pressure curve." When a value is found that is satisfactory the web thickness corresponding to the β is picked off.

This work is long and tedious, and no example is given here.

Section VI.—Further Interior Ballistic Considerations.

114. Energy per pound of powder.—The "potential" of a powder is the total work that could be performed by the unit weight of the products when indefinitely expanded without loss of heat, all the heat being expended in the performance of work.



5 IN 50 CAL GUN	
CAPACITY OF POWDER CHAMBER	1200 CU. IN
WEIGHT OF CHARGE	15 LBS
WEIGHT OF PROJECTILE	60 LBS
TRAVEL OF PROJECTILE	215.6 IN.
MUZZLE VELOCITY	2300 F S

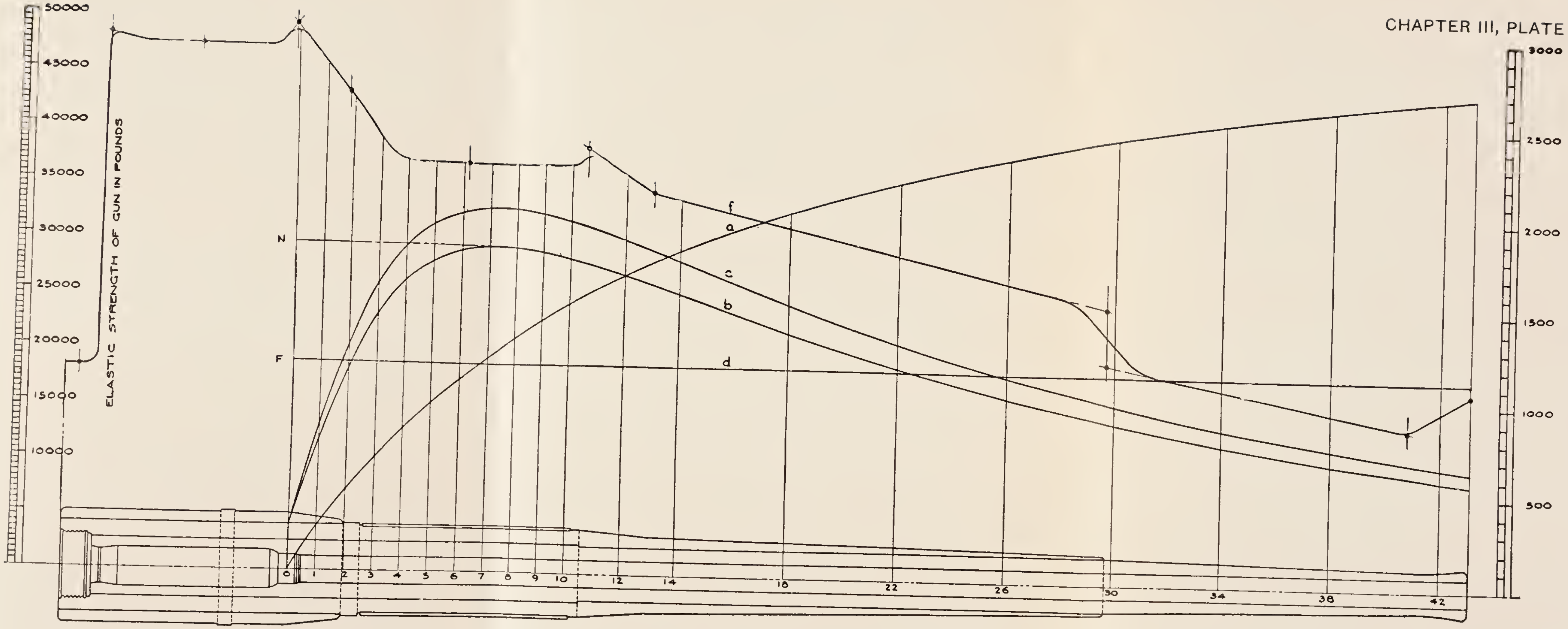
a – VELOCITY CURVE, I.V. 2300 F S

b – PRESSURE CURVE, ENERGY OF THE PROJECTILE.

c – CURVE OF MAXIMUM PRESSURE, b x 1.12.

d – MEAN EQUIVALENT PRESSURE.

f – CURVE OF ELASTIC STRENGTH OF THE GUN.



5$^{\text{IN}}$ 50 CAL. GUN	
CAPACITY OF POWDER CHAMBER	1200 CU. IN.
WEIGHT OF CHARGE	19.2 LBS.
WEIGHT OF PROJECTILE	60 LBS.
TRAVEL OF PROJECTILE	215.6 IN.
MUZZLE VELOCITY	2700 F.S.

a — VELOCITY CURVE, I.V. 2700 F.S.
b — PRESSURE CURVE, ENERGY OF THE PROJECTILE.
c — CURVE OF MAXIMUM PRESSURE, b x 1.12.
d — MEAN EQUIVALENT PRESSURE.
f — CURVE OF ELASTIC STRENGTH OF THE GUN.

The potential of nitrocellulose has been found, by computation, to be about 560 foot-tons per pound of powder.

It is of striking interest to note in connection with the potential of a powder that there is less stored up energy in it than in most of the common fuels and the chief characteristic of an explosive lies in its enormous rate of delivery of energy and not so much in the amount delivered.

The useful work, neglecting recoil, etc., performed per pound of powder in a gun is the quotient of the energy stored in the projectile by the weight of the charge in pounds.

E = energy stored in the projectile, in foot-tons.

e = energy utilized per pound of powder, in foot-tons.

$$E = \tfrac{1}{2} m v^2 \times \frac{1}{2240} = \tfrac{1}{2} \frac{w}{g} v^2 \times \frac{1}{2240}.$$

$$e = \frac{E}{\bar{\omega}} = \frac{w \times v^2}{2 \times 2240 \times g \times \bar{\omega}}. \tag{22}$$

In naval guns the energy obtained from a pound of powder varies from 134 to 184 foot-tons. Consequently the efficiency of the powders varies from 24 per cent to 33 per cent or approximately from one-fourth to one-third. For some few of the low-power smaller-caliber guns the powder energy is as high as 208 foot-tons. The potential of the powder is reduced by many causes that may be defined as the passive resistances to be overcome in a gun. The most important of these resistances are: The forcing of the rotating band of the projectile into the grooves of the rifling; the energy of rotation of the projectile; the friction of the band and the bourrelet along the bore; the resistance of the air while the projectile is in the bore; the acceleration of the charge; the energy of the recoiling parts; the heating of the guns; and the work of expansion of the metal of the gun.

No exact figure can be given for the various amounts of work expended to overcome the passive resistances, but most of the ballisticians agree that the total amount barely reaches 20 per cent of the energy of translation.

Assuming that it reaches 25 per cent, then the total work performed by 1 pound of powder is $e \times 1.25$, or from 30 to 41 per cent. Consequently from 70 to 59 per cent of the energy of the powder is carried away in the atmosphere with the blast when the projectile leaves the muzzle of the gun.

This energy of a powder is an uncertain quantity that varies with the different calibers, the weight of the projectile, and the square of the velocity, and, therefore, it can be neglected in the working up of a design of a gun, there being not much value in the endeavor to use it in such calculations.

115. Powder chamber.—In naval guns the charges of nitrocellulose powder are generally large, and correspondingly the powder chambers must also be large.

Smokeless powders can be fired at high densities of loading, which are only limited by the conditions of suitable powder, good ignition, and the necessity of loading the guns quickly and easily. Some cartridge-case guns have been safely fired at a density of loading as high as 0.80. For bag guns the practical density does not exceed about 0.67. With stacked charges this may be increased to 0.75.

The usual density of loading in naval guns is from 0.40 to 0.70.

In large-caliber guns, to obtain good ignition, each section of the charge has an ignition charge of black powder; but if the ratio of the length of the powder chamber to its diameter is greater than about 7, that precaution may prove insufficient to prevent abnormal pressures. The chambrage, *i. e.*, ratio of diameter of chamber to diameter of bore, should be as small as possible to keep down the weight of the guns and for gun strength; a good average for the chambrage is between 1.1 to 1.25 for our powder. Experience in gun design has forced navy gun designers to the conclusion that they should keep as close to 1.2 as other limiting elements permit. In England, where the questions of chambrage and length of chamber have been very much discussed, it is stated that this can be as high as 1.45. The question of chamber design is very closely bound up with the question of erosion, which latter question is so intricate that it is extremely difficult to obtain a gun that gives a good velocity without a prohibitive pressure and excessive erosion. Our service practice in chamber design has always been conservative, and lies between the English practice of small length and great chambrage and the German practice of long chambers and no chambrage, being like the French practice of keeping moderate dimensions in both directions.

116. Wave pressures.—The hurling back and forth of the powder-gas mass from base of projectile to breech produces a con-

dition in the chamber, known as "*wave pressures,*" of abnormal pressures which, if complete ignition is delayed until the shell has accomplished a part of its travel, may act at a portion of the bore where the gun is not sufficiently strong to withstand them. This phenomenon is akin to "water hammer" in pipes under hydraulic pressure. The only way to avoid such conditions is to fill the chamber instantaneously with a burst of flame that is sufficient to ignite the whole charge. An unsymmetrical charge hinders proper ignition and thus may cause wave pressures. At Sevran-Livry some experiments were made to determine the effect of unsymmetrical charges. When the charge was placed loose in the chamber, the pressure jumped from its normal value of 13.9 tons to 34 tons per square inch. The same powder fired in a closed chamber at the same density of loading (0.335) would have given only 20.8 tons.

As a rule, the space occupied by the charge may be considered as fairly distributed in the powder chamber; but with a small charge, keeping it close to the primer vent, the greater portion of the vacant space is between the charge and the projectile. This is more pronounced when the chamber is long and narrow, and in these conditions wave pressures may be produced. But we must not forget that the conditions necessary for wave pressures are the firing of a very quick powder at a density sufficiently high to produce about 14 tons maximum pressure. Cases of this kind have occurred with densities of loading of about 0.32, although slower powders with the same density of loading gave no wave pressures.

117. Temperature of charge in gun.—Differences in temperature of the charge affect the rate of combustion, varying directly with the temperature. Long series of tests have been conducted at the naval proving ground to determine the effect upon velocity, using powder at different temperatures. It is found that the effect varies somewhat with the size and grain of the powder, but in general it may be taken that for every increase of 1° F. in temperature there is occasioned an increase in velocity of 2 foot-seconds.

118. Solvent and moisture.—As solvent and moisture may be considered chemical ingredients of powder, variations in the content of each may be expected to produce changes, such as are

produced by differences in nitrogen content. This is found to be the case, experimentally; within ordinary variations moisture causes the same effect as solvent, or, as it increases, makes the powder slower.

119. Temperature of metal in gun after repeated firing.—Numerous tests have been made to determine the temperature of the gun and mushroom head after repeated firings. The highest temperatures recorded after firing 29 rounds from a 5-inch 50-caliber gun in 3 minutes 45 seconds were mushroom face 275° F., muzzle 304° F. These temperatures did not affect a powder charge left in the gun in contact with the hot mushroom for 4 minutes. Fifty rounds from a 3-inch 50-caliber gun after 110 rapid rounds showed a maximum temperature of 394° F.

These temperatures are taken in guns without operation of the gas-ejection system. The effect of the latter is materially to cool the powder chamber and bore, but the mushroom temperature is, since the breech is open during the operation of the gas-ejecting blast, not affected thereby.

So far as the ballistic conditions of the gun are concerned, it is evident that the increased heat of the bore will heat the powder charge and so cause increase in velocity, provided the charge is left for any considerable time in the bore of the gun. When fired shortly after loading no increase of velocity will be produced from this cause.

120. Heat cracks.—At each discharge of a gun the metal at the surface of the bore is heated to a temperature that would cause it, if free, to expand a great deal more than it can stretch within its elastic limit, its free expansion being prevented by the outer metal (which remains comparatively cool); it takes a permanent set in compression, or, in other words, is crushed; then, when it cools, it is held in a state of tension by the outer metal. Or, in the case of a built-up gun, it is less compressed than it was. The usual result is that the surface of the bore, more and more, assumes a state of circumferential tension and ends by developing longitudinal cracks, called heat cracks.

These cracks appear most prominently at the bottoms of the grooves of the rifling, at the root of the driving edges of the land when the grooves are hook shaped, and at both corners of square sectional grooves; and they work farther and farther into the

metal as the use of the gun continues, but do not, in the "accuracy-life" of the gun, become deep enough to reduce the strength of the gun.

121. Erosion.—Erosion is the gradual enlargement of the bore and smooth wearing away of its surface by the action of the powder gases, beginning in rear of the rifling and extending farther and farther down the bore as the firing is continued. This wear is greatest at the origin of rifling and is about twice as great on the lands as in the grooves, so that its effect is to make the bore slightly conical from the front of the powder chamber forward and to gradually obliterate the rifling.

The necessary and sufficient conditions for gun erosion are the intense heating of a thin film of metal at the surface of the bore and the rush of the gases over that surface. The temperature must not only be high enough, but must be maintained long enough to bring the surface to the friable point. The weight of powder charges increases practically as the cube of the caliber, while the surface for absorbing the heat increases only with the square of the caliber. Therefore it is apparent that the bores of large guns are hotter than are those of guns of small caliber. The time action of the powder is greater in the large than in the small gun, being approximately proportional to the caliber of the gun. With similar conditions it is universally found that the erosion is greatest in the large caliber guns.

That the rush of the mass of gases over the heated surface is a requisite for erosion is shown by the fact that the rear part of the powder chamber is not worn by repeated firings nor is the interior surface of a bomb in which powder charges are burned for experimental purposes.

(1) Erosion as it actually occurs in any gun thus depends upon:

a. Temperature of combustion and the pressure.

b. Weight of the powder charge.

c. Time of action, *i. e.*, duration.

d. Velocity of the movement of gases over heated surface.

Erosion as it washes away the rifling and enlarges the bore near the origin causes a reduction in pressure and velocity with the ultimate condition that the obliteration of the rifling will result in the projectiles giving inaccurate flights.

Erosion also enlarges the heat cracks and thus actually weakens the gun.

On the "Powder Test Sheet" of the 12-inch 50 gun it is seen that the loss given as due to erosion is 83 foot-seconds in muzzle velocity and 2 tons in pressure, *after but 53.2 equivalent service rounds.* Before guns are installed on shipboard they are "proved" by firing at least five rounds, one of which is at the proof pressure, that is, at a pressure 25 per cent above the service or working pressure, though much less than the elastic strength of the gun. When considering the erosion wear such a round is counted as more than one service round while rounds fired at less than service pressure are counted as less than a service round. The decrease in initial velocity of 83 foot-seconds will cause a decrease in the range of this gun at 15,500 yards of 643 yards. So long as all guns of a ship's battery have been fired an approximately equal number of times, the erosion of the entire battery is constant, and a correction to the sight-bar range can be applied to compensate for the erosion of all the guns.

(2) Naturally great efforts have been made to discover methods of combating erosion. Briefly speaking, there have been tried:

a. Different metals for the gun tubes.

b. Plating the gun tube with various metals and alloys.

c. Adding to the charge, for lubrication of the bore, ozokorite (which also had the effect of reducing the temperature of combustion), graphite, and vaseline.

d. Special seats for rotating band.

e. Variations in rifling.

f. Variations in powder chambers.

Nothing has been found that will reduce it.

The following methods have been adopted and are practiced:

a. Using reduced charges for target practice. These are charges approximately three-quarters of the service charges, giving much lower velocities. The reduced velocity of the 12-inch guns is 2100 foot-seconds; for all 14-inch guns, 2000 foot-seconds; for 5-inch guns, 2300 foot-seconds; and so on. Four such rounds erode the gun about as much as one service round.

b. The twist of the rifling has been made a uniformly increasing one of from one turn in 50 calibers to one turn in 32 calibers for large guns, and one turn in 25 calibers for smaller guns.

c. In the British Navy rotating bands are augmented by a ring of copper fitted over the standard band, the shell thus being seated at its normal position in the bore despite the erosion.

d. All major guns are now built with conical liners which when worn are removed from the gun, new liners then being installed, an operation requiring from four to six weeks for a large gun.

122. Life of guns.—This is the number of service rounds that can be fired by a gun before it loses its accuracy or loses sufficient energy to warrant its condemnation.* Were it not for erosion the life of a gun would be indefinite. There is a case of a large gun having been relined 14 times and still being serviceable. The limit of accuracy-life of the gun is set at the first "tumble," or failure, due to insufficient rotation, caused by lack of rifling, to fly true.

123. Droop.—This is caused by the lack of longitudinal rigidity in the gun itself or by the heat strains of unequal cooling during manufacture. In both cases perceptible modifications of the droop are brought about by firing or by the heating effect of mere sunshine.

The droop of guns must be minimized as far as is practicable and the stiffest possible gun be constructed in order that similar guns may shoot alike and that the vibrations produced upon firing may be minimized. Hoops as long as possible are used, being locked together in order to reduce play at parts as far as possible.

124. Gun design.—To sum up how the powder affects the design of the gun: The quantities, caliber, weight of projectile, and muzzle velocity are decided upon. Particular attention has to be given to the powder in order that the dimensions of the powder chamber, length of gun, and the necessary thickness of tubes and hoops may be calculated. The foregoing elements constitute what is called the "gun project." A larger charge of a powder that is slow for a gun is manifestly required, as compared to the weight of charge of a quicker powder. The larger charge requires a larger chamber space, thus increasing the diameter of the chamber over that of the gun. The maximum pressure being less, the gun may be less strong and therefore lighter at its breech but stronger and heavier along its chase. If the diameter of the chamber is already too great, the gun must be lengthened to obtain the desired velocity.

Quicker powders give very high and dangerous pressures in the powder chamber requiring excessive thickness of walls over

* A 14-inch 45-caliber navy gun has fired 209 rounds with no "tumble."

the powder chamber, the gun being shorter and weaker along its chase, and serious erosion accompanies high pressures. The probable erosion, varying as it does with the pressure, figures largely in fixing the pressure to be allowed.

The limiting pressure being decided upon, by methods of successive approximations the design and dimensions of the powder chamber are calculated from the ballistic formulas, the pressures at the various points of the bore and the expected muzzle velocity are then determined, and a conference is then usually held in which various conflicting elements are considered and the dimensions finally decided upon.

Thus the interior ballistic formulas play the all important part in the design of modern ordnance.

Next the formulas of elastic strength are used and the design is made. These formulas compute the points that compose the strength curve of the gun.

125. The instruments used, and method of use, to find the actual pressures and velocities for comparison with the pressures and velocities found from the foregoing formulas of Interior Ballistics, are described in paragraph *792 et seq.*

CHAPTER IV.

RECOIL AND RECOIL BRAKES.

126. All modern guns, including those of the U. S. Navy, are mounted so as to permit recoil when fired.

The recoil movement is introduced to reduce the forces otherwise acting on the mount and ship's structure, and, by the reduction of these forces, to produce the lightest weight of mount practicable for use aboard ship.

In the case of a gun having no recoil, the force acting on the mount, due to the firing of the gun, is the product of the area of the bore and the effective powder chamber pressure. This force amounts to several million pounds in the case of major caliber guns and is of considerable magnitude for all calibers of modern naval guns. From this, it is obvious that, for a gun having no recoil, the proportions of the mount would be unreasonably large, making it cumbersome to handle and, on account of weight, unsuitable for use aboard ship.

By permitting the gun to recoil a limited distance the forces which would otherwise act on the mount are greatly reduced and can be regulated to suit the character of the vessel for which the mount is designed, and thus make possible the use of larger caliber guns aboard ship than would otherwise be practicable.

The movement of the gun to the rear as a result of the work done upon the gun by the powder gases is known as the *recoil,* and the length of this movement as the *length of recoil.*

The return movement of gun to battery after firing is known as the *counter-recoil,* and is equal in amount to the recoil.

Recoil generally takes place in the direction of the axis of the gun, as in Fig. 8. But in special cases where it is necessary to clear a deck of a vessel or platform of a car, as in some types of railway mounts, the recoil takes place parallel, or slightly inclined, to the deck or platform, as in Fig. 9. Occasionally, as in the case of anti-aircraft mounts, it is necessary to vary the length of recoil to suit the elevation, as in Fig. 10, in order to clear the deck at the higher angles of elevation.

The type of mounting and recoil represented by Fig. 9 is not adapted to the higher angles of elevation, since the recoil serves only to reduce the component of the firing force in the direction of the recoil. As the angle of elevation increases, the component of the firing force acting in the direction of recoil decreases and approaches zero as a limit, whereas the component of the firing force acting normal to the direction of recoil increases and approaches the full breech pressure as a limit. The effect of this is that for angles of elevation approaching 90° the full effect of the breech pressure is transmitted directly to the mount. Mounts of this type are built to meet special conditions where the maximum angle of elevation does not exceed 40°.

Usually the length of recoil varies with the size of the gun and the type of the mount. Mounts of destroyers, and small light vessels, have a longer recoil than mounts for battleships and battle cruisers, where the deck structure is more substantial and capable of sustaining greater forces.

Where the gun recoils in the mount, *the forces acting on the mount depend on the resistance offered by the mount to the recoil of the gun* rather than on the chamber pressure and the diameter of the bore. For the same gun and the same powder pressure curve, the forces acting on the mount vary inversely as the length of recoil. For major caliber guns of battleships, the length of recoil is limited to about three calibers on account of the restrictions offered by the barbette of the turret; for destroyers, where the deck structure is light and incapable of sustaining large forces, the length of recoil is considerably increased and is usually six calibers or more in length.

As a rule, it will be found there is some limitation on the length of recoil imposed by the ship's structure, and that the determination of the proper length is compromised by other conditions. In the case of turret mounts, an increase of recoil results in a larger barbette diameter and greatly increased weights as a consequence. In the case of minor caliber guns, longer recoil results in increased trunnion heights in order that the breech of the gun shall clear the deck at extreme elevation and at maximum recoil.

After the length of recoil has once been determined to suit the practical conditions to be considered in each case, the problem with which we are concerned is the absorption of the recoil of the

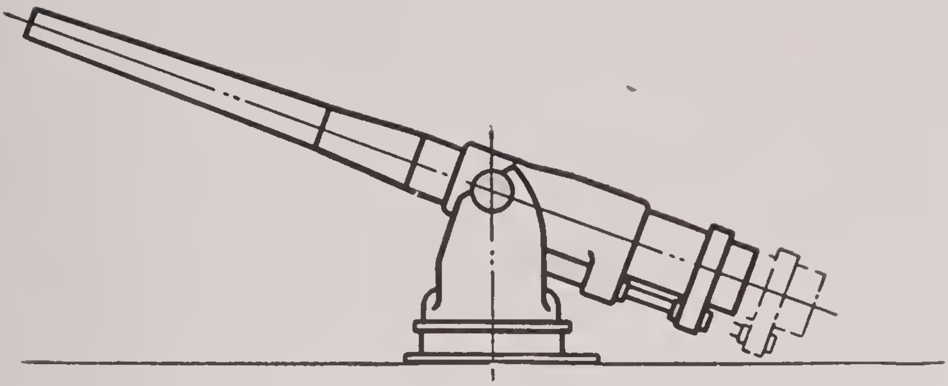


Fig. 8.

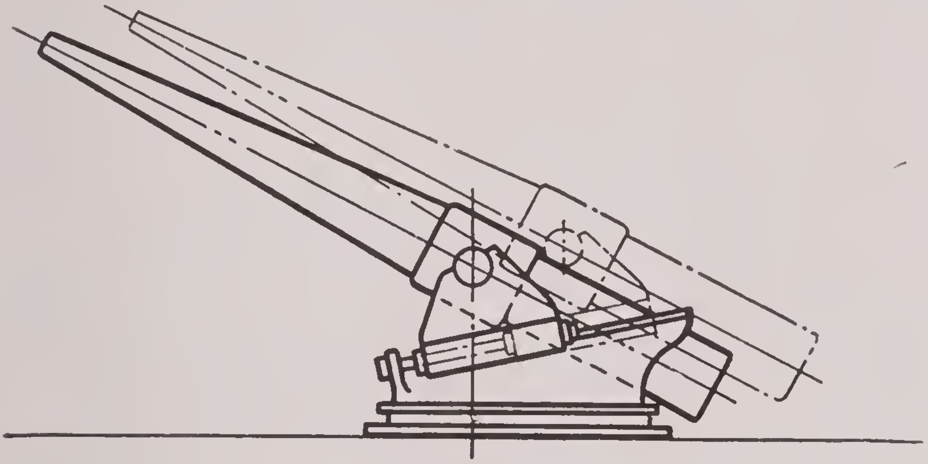


Fig. 9.

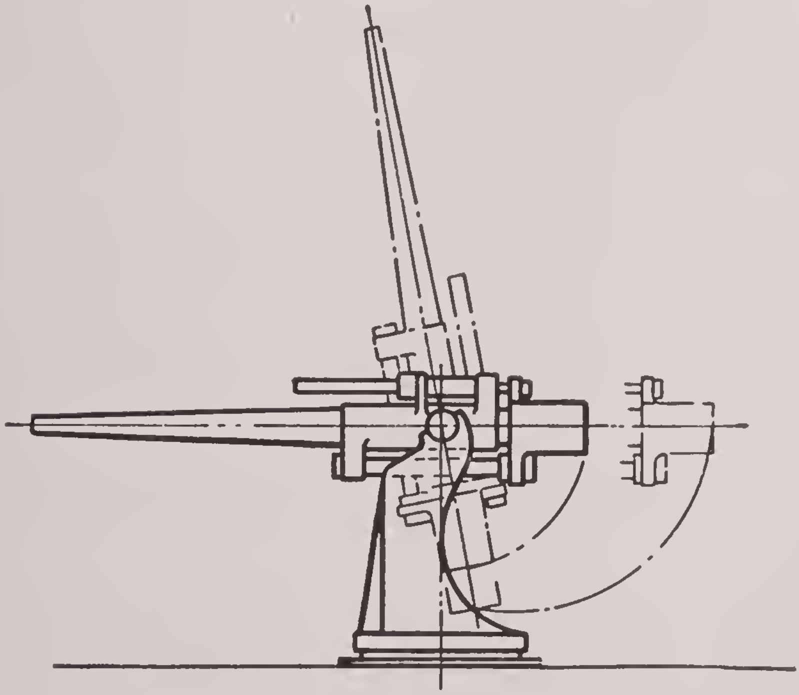


Fig. 10.

moving parts in the most efficient manner. It is obvious that the most efficient distribution of forces will exist when the resistance to recoil is constant throughout the full length of recoil.

In all service mountings, the major portion of the energy of recoil is absorbed by the hydraulic brake comprising the principal part of the recoil system. The counter-recoil system and the friction of the gun in the slide contribute a small part of the resistance to recoil, whereas the gravity component of the recoil weights exerts a varying effect as the gun is elevated.

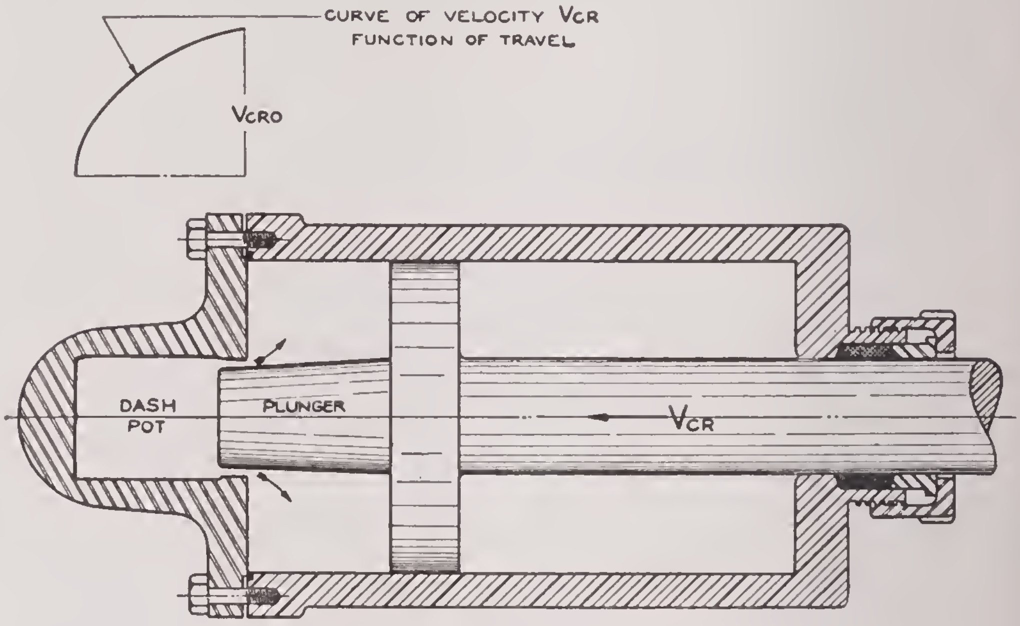


FIG. 11.

The advantages of the hydraulic brake can be attributed to the large amount of energy that can be absorbed in an unconvertible form; to its simplicity and reliability; and to the facility with which the resistance offered to the movement of the gun can be regulated. The energy absorbed is converted into heat and dissipated by the mount into the atmosphere. Springs or compressed air are not suitable for checking the recoil of guns on account of the limited amount of energy that can be absorbed, and also because the energy absorbed during recoil is returned again to the mount during counter-recoil.

A simple form of hydraulic brake is illustrated in Fig. 11. This form of brake is used extensively for checking the motion of heavy moving parts, and corresponds to the form of brake used

in turret and broadside mounts for checking the return movement of the gun to battery in counter-recoil.

In all forms of the hydraulic brake, including that of the recoil system of gun mounts, the brake consists of four simple elements, viz., cylinder, piston, liquid and some form of orifice connecting the ends of the cylinder each side of the piston. The motion of the piston within the cylinder forces the liquid through the orifice from one side of the piston to the other. The work required to force the liquid through any given orifice can be definitely determined from the laws of hydraulics and depends upon the area of the orifice, the area of the piston, the velocity of the piston, and the weight of the liquid.

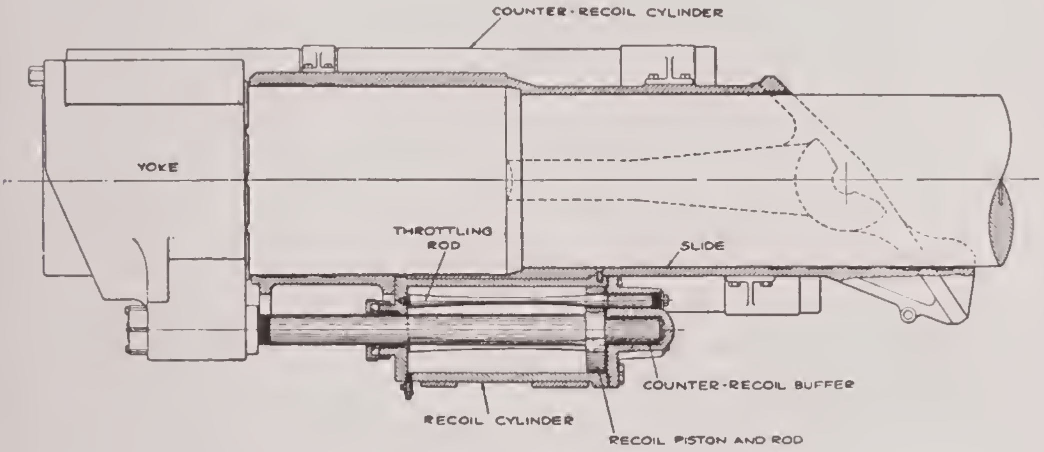


FIG. 12.—TYPICAL RECOIL SYSTEM FOR TURRET MOUNTS.

It is obvious that the work done on the piston is equivalent to the work done on the liquid. The work done on the piston is utilized to overcome the movement of the gun during recoil, whereas the work done on the liquid during the same time is indicated by a rise of temperature of the liquid. It can be shown that the work absorbed by the hydraulic brake can be fully accounted for in the rise of temperature of the liquid. Under rapid fire conditions, the temperature rise is accumulative from shot to shot and results in a considerable rise of temperature which must be taken into account in designing the recoil system.

In the application of the hydraulic brake to gun mounts, the recoil cylinder is usually attached to the slide and the piston to the gun by means of the piston rod and gun yoke. Fig. 12 shows a typical installation for turret mounts. The hydraulic brake is so

proportioned that the total resistance offered by the recoil system, counter-recoil system, and friction, with a proper allowance being made for gravity forces, is constant and of sufficient magnitude to bring the gun to rest in the prescribed distance. With the resistance constant, the velocity of the gun during recoil will vary from zero at the beginning to a maximum and back again to zero at the termination of recoil. As a result of this varying velocity, the area of the orifice will vary for all portions of the recoil, and on this account it is necessary to provide means to vary the area of the orifice for all positions of the recoil to suit the velocity of

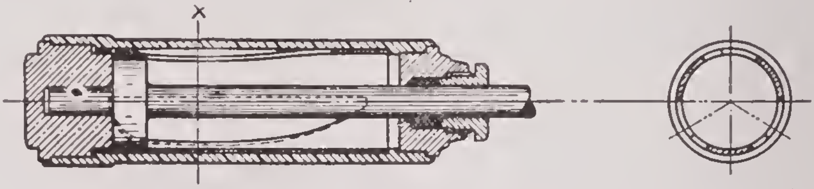


FIG. 13.

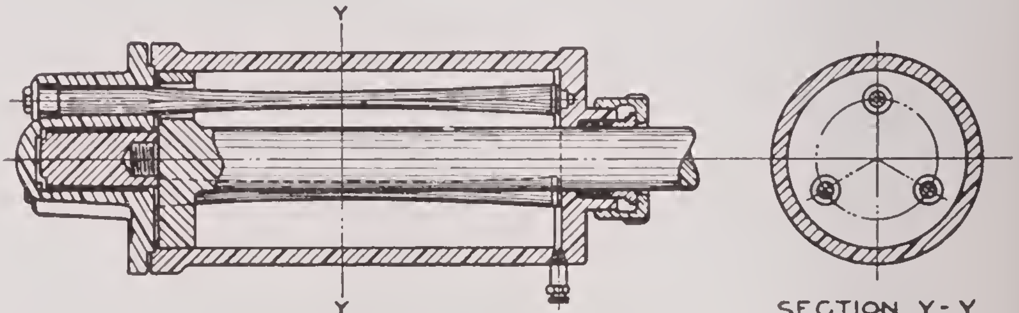


FIG. 14.

recoil at each point. This is accomplished in various ways as illustrated by Figs. 11, 13, and 14.

In Fig. 11 the diameter of the dash pot is constant and the area of the orifice is varied for different points of the stroke by varying the diameter of the plunger.

Fig. 13 shows the usual method of forming the orifice in the recoil cylinders of minor caliber gun mounts. A groove of constant depth is cut in the wall of the recoil cylinder, the width of the groove varying to suit the velocity of recoil; from two to three such grooves are arranged around the inner surface of the cylinder in a symmetrical pattern. In case two or more recoil

cylinders are used, the arrangement of grooves in all cylinders is similar and the cylinders are interconnected to equalize the pressure in all cylinders.

Fig. 14 illustrates the usual method of varying the orifices in turret mounts. Two or three rods are passed through apertures in the piston; the rods are attached to the ends of the recoil cylinders as shown. By varying the diameter of the rods, the proper variation in the area of the orifice for all points of the recoil may be obtained.

127. The principles controlling the action of the hydraulic brake.—The principles controlling the action of the hydraulic brake are simple and may be understood from the analysis of the hydraulic brake illustrated in Fig. 11. The following symbols will be used, all units being expressed in terms of pounds, feet and seconds:

W_r = Weight of the moving parts (plunger) in pounds.

M_r = The mass of the moving parts $= \frac{W_r}{g}$.

R_{cr} = The total resistance in pounds offered to the movement of the plunger.

V_{cr} = Velocity of the plunger at any time t.

V_{cr_0} = The maximum velocity in feet per second of the plunger at the time the plunger enters the dash pot.

V_{1r} = Velocity in feet per second of the liquid through the orifice at any time t.

γ = The weight of a cubic foot of liquid in the dash pot. (76 pounds for usual naval liquid, 80 per cent glycerine and 20 per cent water.)

g = Acceleration of gravity $= 32.16$.

A_r = The effective area of the plunger in square feet.

a_r = The area of the orifice in square feet at any time t.

S_{cr_1} = The full stroke of the buffer in feet.

S_{cr} = The stroke of the buffer corresponding to velocity V_r.

α = Negative acceleration (or retardation).

In Fig. 11 the velocity of the plunger upon entering the dash pot is expressed by the letter V_{cr_0}, and the weight of the moving

mass of the plunger, and the parts to which it is attached, by W_r, in which case the energy of the moving mass is

$$E = \frac{W_r V^2_{cr0}}{2g}. \tag{1}$$

As the plunger enters the dash pot, the liquid escapes through the orifice formed by the plunger and dash pot, in the direction indicated by the arrows.

The resistance set up by the liquid as it escapes through the orifice acts on the end of the plunger. The amount of resistance exerted depends on the area and velocity of the plunger; the area of the orifice through which the liquid escapes; and the weight of the liquid. The area of the orifice may be varied throughout the stroke of the plunger by giving the proper form to the plunger. It is customary to vary the area of the orifice so that the resistance offered to the motion of the plunger will be constant throughout the stroke; in which case the work of resistance opposing the motion of the plunger may be expressed

$$\text{Work of resistance} = R_{cr} S_{cr1}. \tag{2}$$

The value of the resistance R_{cr} must be of sufficient magnitude to bring the plunger to rest in the distance S_{cr1}, in which case we may write

$$R_{cr} S_{cr1} = \frac{W_r V^2_{cr0}}{2g}. \tag{3}$$

From equation (3), the value of the resistance R_{cr} necessary to bring the plunger to rest in the distance S_{cr1} is

$$R_{cr} = \frac{W_r V^2_{cr0}}{2g S_{cr1}}. \tag{4}$$

The volume of liquid that passes through the orifice is the volume of liquid displaced by the piston. We therefore have at any instant

$$V_{cr} A_r = V_{1r} a_r.$$

Or, for the velocity of flow

$$V_{1r} = \frac{V_{cr} A_r}{a_r}. \tag{5}$$

From Torricelli's law, for the flow of liquid through an orifice, we know that the pressure required to produce this velocity of

flow is the pressure due to a column of liquid whose height in feet is given by the equation

$$V^2_{1r}=2gh. \qquad (6)$$

Substituting in equation (6) the value of V_{1r} from equation (5) and solving for h, we obtain

$$h=\frac{V^2_{cr}A_r^2}{2ga_r^2}. \qquad (7)$$

The weight of a cubic foot of liquid being γ, the weight of the column whose area of cross-section is one square foot will be γh. And the weight of the column whose area of cross-section is equal to that of the plunger will be $A_r\gamma h$. Therefore, $A_r\gamma h$ is the pressure on the piston. Substituting in this expression the value of h from equation (7), we have, for the total pressure on the piston, for any velocity V_{cr}

$$R_{cr}=\frac{\gamma A_r^3V^2_{cr}}{2ga_r^2}. \qquad (8)$$

This equation is general; and expresses the relationship between R_{cr}, A_r and a_r, for any given velocity of the plunger.

Solving for a_r^2, we obtain

$$a_r^2=\frac{\gamma A_r^3V^2_{cr}}{2gR_{cr}}. \qquad (9)$$

From equation (9) it will be seen that the area of the orifice may be determined for any portion of the stroke of the plunger, if the pressure R_{cr} and velocity of the plunger at that point are known.

To determine the velocity of the plunger, we know that when the total resistance to the movement of the plunger is constant the retardation is constant; and we may express the relationship between velocity, space and retardation by the expression

$$V^2_{cr}=2aS_{cr}. \qquad (10)$$

By substituting in this expression the known values of V_{cr} and S_{cr} at the point where the plunger enters the dash pot, we may determine the value of the retardation constant, for the particular buffer under consideration. Substituting the value for retardation thus obtained for a in equation (10), and treating V_{cr} and S_{cr} as variables, we may obtain the value of the velocity for all points of the stroke. It will be observed from equation (10) that the

velocity curve is a parabola with its origin located at the bottom of the dash pot. (See Fig. 4.)

By substituting the value of V_{cr} in each case, in equation (9), the area of the orifice for all points of the buffer may be obtained.

Equation (9) makes no allowance for the friction of the liquid and the contraction of the liquid vein as it emerges from the dash pot. This is provided for in actual practice by adding from 15 per cent to 30 per cent to the area of the orifice computed by equation (9). The particular factor applying in each case depends on the shape of the orifice formed between the dash pot and the end of the plunger, the larger factor being used where the corner of the plunger is square, and the smaller factor where a radius is formed on the end of the plunger. Intermediate factors are used which depend on the shape of the orifice.

The liquid used in the dash pots and recoil cylinders of the navy is composed of a solution of 80 per cent glycerine and 20 per cent water, which weighs about 76 pounds per cubic foot. This liquid has a low freezing point and fairly constant viscosity within the ordinary temperature ranges, and has given satisfactory results in naval mounts for a great many years. Certain grades of buffer oil of the same weight give equally good results.

Equation (9) can be used for computing the area of orifice of any form of hydraulic brake when all the circumstances regarding velocity of retarded recoil and variations in pressure are known for all points of the stroke.

The proper allowances for all forces acting on the gun can be made easily after all other circumstances of recoil due to the action of the powder gases are determined. The effect of the powder gases on the recoil motion of the gun may be determined in the following manner:

128. Velocity of free recoil.—Since the proper allowance can be made for the elevation of the gun and action of gravity and other forces after the other factors are determined, it is first assumed that the gun is mounted in a horizontal position and is acted on by the pressure of the powder gases unopposed by friction or brake. The parts of the system acted on by the powder gases are the gun, the projectile, and the powder charge [including the burned and unburned portions of the charge at any instant]. The curve of velocity of free recoil of the gun during the time of

the discharge of the projectile will be similar to the curve of velocities for the projectile and powder gases during the same time, except to a reduced scale on account of the differences in masses. From the momentum of the projectile and powder gases, the momentum of the gun may be determined. Since the momentum of the gun at any time is equal to the sum of the momentum of the projectile and powder gases, we may write

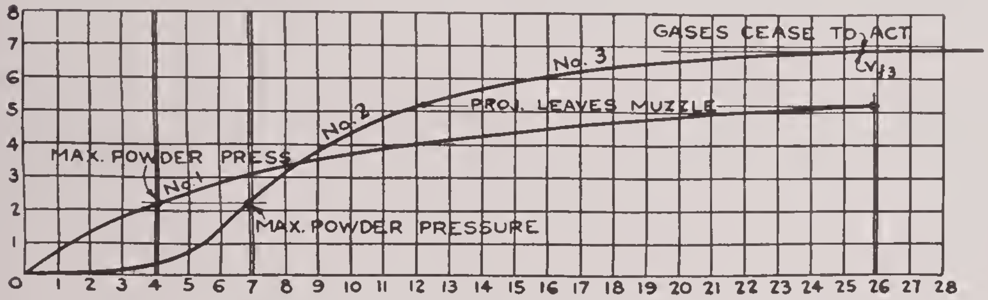
$$M_r V_f = m V_p + \bar{m} V_c. \qquad (11)$$

M_r, m, and $\bar{m}$ representing the masses of the gun, projectile and powder charge, respectively; and V_f, V_p, and V_c the velocity of these masses.

The velocity of the projectile at any point in the bore of the gun, expressed as a function of the travel of the projectile in the bore, is determined from equations on Interior Ballistics (Chapter III). These equations assume that the velocity-space curve of the projectile in the bore is a hyperbola,

$$V_p = \frac{au}{b+u}, \qquad (12)$$

NOTE:-THE CURVES BELOW WERE LAID DOWN FOR A 16-INCH MOUNT. THE CURVES WILL VARY TO SUIT EACH TYPE AND CALIBER OF MOUNT.



NO.	DESIGNATION OF CURVES		HORIZONTAL SCALE	VERTICAL SCALE
1	VELOCITY OF PROJECTILE	FUNCTION OF SPACE	1 DIVISION = 2 FT	1 DIVISION = 500 F.S.
2	VELOCITY OF PROJECTILE	FUNCTION OF TIME	1 DIVISION = .004 SEC	1 DIVISION = 500 F.S.
3	VELOCITY OF FREE RECOIL (RECOILING PARTS)	FUNCTION OF TIME	1 DIVISION = .004 SEC	1 DIVISION = 5.084 F.S.

FIG. 15.

where a and b are parameters determined by equations (13) and (14).

V_p = Velocity of projectile at any point in the bore in feet per second.

$$a = 6823\Delta^{\frac{1}{12}}\left(\frac{W}{P}\right)^{\frac{1}{3}}. \qquad (13)$$

Δ = Density of loading (varies from .4 to .7).

w = Weight of charge in pounds.

p = Weight of projectile in pounds.

By transposing equation (12) and substituting the total travel u_1 for u and the corresponding velocity at the muzzle V_{p_1} for V_p, we get the parameter b in feet:

$$b = \frac{au_1}{V_{p1}} - u. \tag{14}$$

The velocity of the center of mass of the powder charge is unknown. It is obvious, however, that if the charge were instantaneously converted into gases the mean velocity would be one-half the algebraic sum of the velocities of the gun and the projectile. Assuming this to be true, and also that the velocity of the breech at the instant the shell leaves the muzzle is zero, we may without great error substitute in equation (11) $\frac{V_p}{2}$ for V_c. Making this substitution and replacing masses by weights, we have

$$W_r V_f - (p + .5\overline{W}) V_p = 0. \tag{15}$$

Multiplying equation (15) by time, (t), and substituting S_f for $V_f t$ and u for $V_p t$, we may write

$$W_r S_f - (p + .5\overline{W}) u = 0, \tag{16}$$

where S_f is the space travelled in free recoil, and W is the travel of the projectile.

Substituting the value of V_p from equation (12) in equation (15) and transposing,

$$V_f = \frac{(p + .5\overline{W})}{W_r} \frac{au}{b + u}, \tag{17}$$

and

$$V_{f_1} = \frac{(p + .5\overline{W})}{W_r} V_{p1}, \tag{18}$$

V_{f_1} being the velocity of free recoil when the projectile leaves the muzzle.

From equation (16), we have

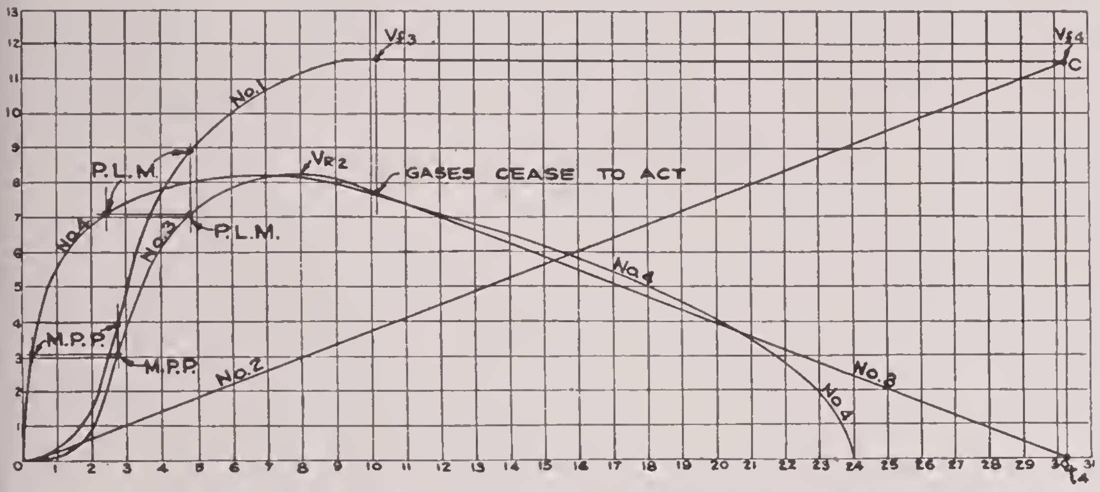
$$S_f = \frac{(p + .5\overline{W})}{W_r} u. \tag{19}$$

At time t_1, u is equal to u_1. We may, therefore, express the space passed over by the recoiling parts at the time t_1, the time when the projectile reaches the muzzle, by the following equation:

$$S_{f_1} = \frac{(p + .5\overline{W})}{W_r} u_1. \tag{20}$$

The value V_{f1}, equation (18), is not the maximum velocity of free recoil, since sufficient pressure still exists in the gun for a short time after the shell leaves the muzzle to further increase the velocity of free recoil of the gun.

The time the gases continue to act after the projectile leaves the muzzle, and the maximum velocity attained by these gases, are not definitely known. Measurements taken by a Severt velocimeter, however, indicate that for the usual muzzle velocities [*i. e.*,



NOTE: M.P.P. DENOTES POINTS OF MAXIMUM POWDER PRESSURE.
P.L.M. DENOTES POINTS WHERE PROJECTILE LEAVES MUZZLE

NO.	DESIGNATION OF CURVES		HORIZONTAL SCALE	VERTICAL SCALE
1	VELOCITY OF FREE RECOIL (ALL RECOILING PARTS)	FUNCTION OF TIME	1 DIVISION = 0.01 SEC.	1 DIVISION = 3 F.S.
2	RETARDATION OF ALL RECOILING PARTS	FUNCTION OF TIME	1 DIVISION = 0.01 SEC.	1 DIVISION = 3 F.S.
3	VELOCITY OF RETARDED RECOIL (RECOILING PARTS)	FUNCTION OF TIME	1 DIVISION = 0.01 SEC.	1 DIVISION = 3 F.S.
4	VELOCITY OF RETARDED RECOIL (RECOILING PARTS)	FUNCTION OF SPACE	1 DIVISION = 2.0	1 DIVISION = 3 F.S.

NOTE: THE ABOVE CURVES WERE LAID DOWN FOR A 16-INCH MOUNT. THE CURVES WILL VARY TO SUIT EACH TYPE AND CALIBER OF MOUNT.

FIG. 16.

from 2100 foot-seconds to 3150 foot-seconds] the correct values of the maximum velocity of free recoil may be obtained from equation (18) by substituting for one-half $\overline{W}V_p$ the value $4700 \times \overline{W}$, in which case we may write, for the maximum velocity of free recoil (V_{f3}),

$$V_{f3} = \frac{pV_p + 4700\overline{W}}{W_r'}. \tag{21}$$

It should be noted that the coefficient 4700 applies only to smokeless powder for the velocities mentioned. (NOTE.—For black powders, 3000 should be used for corresponding velocities.) Also

that equation (21) applies only in the case of free recoil and does not express the velocity of retarded recoil. It is necessary that we know the velocity of retarded recoil at all points of the recoil in order to determine by means of equation (9) the correct form of the orifice to be provided at all points to bring the gun to rest in the desired distance.

The velocities for retarded recoil will be determined in a manner hereinafter described.

129. Computation of velocity of retarded recoil.—The various steps necessary to determine the velocity of retarded recoil in order that we may compute the area of the throttling orifice by equation (9) are as follows:

1st. Compute the curve of velocities of the projectile in the bore function of space. (See Curve No. 1, Fig. 15.)

2d. Compute the curve of velocities of the projectile function of time. (See Curve No. 2, Fig. 15.)

3d. Compute the curve of velocities of free recoil of recoiling parts function of time. (See Curve No. 1, Fig. 16.)

4th. Compute the curve of retardation function of time. (See Curve No. 2, Fig. 16.)

5th. Compute the curve of velocities of retarded recoil function of time. (See Curve No. 3, Fig. 16.)

6th. Compute the velocity of retarded recoil function of space. (See Curve No. 4, Fig. 16.)

Having determined the velocities of retarded recoil, function of space, equation (9) may be used for computing the area of the throttling orifice for all positions of the recoil when the brake force, counter-recoil force, gravity force, and friction force for each part of the recoil are known.

Velocity of projectile—function of space.—Equation (12) gives the velocities of the projectile in the bore, function of space (travel of projectile).

Velocity of projectile—function of time.—To determine the time of travel of the projectile in the bore from equation (12), we may substitute the values of

$$\frac{au}{b+u} \text{ for } V$$

in the following equation which expresses the relation between time, velocity, and space when the velocity is variable,

$$dt = \frac{du}{V}, \tag{22}$$

or, substituting $\frac{au}{b+u}$ for V,

$$dt = \frac{du}{\frac{au}{b+u}}. \tag{23}$$

Transposing and integrating,

$$t = \int \frac{(b+u)}{au}\, du. \tag{23-1}$$

$$t = \int \frac{b\,du}{au} + \int \frac{u\,du}{au}. \tag{23-2}$$

$$t = \frac{b}{a}\int_0^u \frac{du}{u} + \frac{1}{a}\int_0^u du. \tag{23-3}$$

$$t = \frac{b}{a}\log_e u + \frac{u}{a} + \text{constant } c. \tag{23-4}$$

When u is equal to 0, t is equal to 0, and $\log_e u$ is equal to infinity, and we cannot determine the constant of integration (c) without imposing an assumed condition.

It is reasonable to assume that for extremely small values of u the time will be approximately the same, whether the velocity-space curve is a hyperbola or a parabola.

It has been found from investigation that when the value of u is equal to $\frac{b}{100}$, the time equations for the two curves could be equated and the constant of integration for equation (23-4) determined with considerable accuracy.

Assuming the velocity curve, function of space, is a parabola, we may write

$$V_p = \sqrt{2pu}. \tag{24}$$

Substituting the value of V_p from equation (24) in equation (22) [which expresses the relation between time, velocity and space, when the velocity is variable], we have

$$dt = \frac{du}{\sqrt{2pu}}. \tag{24-1}$$

Transposing and integrating,

$$t=\int\frac{u^{-\frac{1}{2}}du}{\sqrt{2p}}=\frac{2u^{\frac{1}{2}}}{\sqrt{2p}}\,; \tag{24-2}$$

from equation (24)

$$\sqrt{2p}=\frac{V_p}{\sqrt{u}}\,. \tag{24-3}$$

Substituting the value of $2p$ from equation (24-3) in equation (24-2), we have

$$t=\frac{2u^{\frac{1}{2}}}{\dfrac{V_p}{\sqrt{u}}}=\frac{2u}{V_p}\,. \tag{24-4}$$

The time for the parabola up to the point where $u=\dfrac{b}{100}$ is

$$t=\frac{2u}{V_p}=2\times\frac{b}{100}\times\frac{101}{a}=\frac{202b}{100a}=2.02\frac{b}{a}\,, \tag{25}$$

since

$$V_p=\frac{au}{b+u}=\frac{ab}{100}\times\frac{100}{101b}=\frac{a}{101}\,.$$

The time for the hyperbola up to the point where u is equal to $\dfrac{b}{100}$ is

$$t=\frac{b}{a}\log_e\frac{b}{100}+\frac{b}{100a}+c. \tag{25-1}$$

Equating the values of t given by equations (25) and (25-1) and solving for c, we have

$$c=2.02\frac{b}{a}-\frac{b}{a}\log_e\frac{b}{100}-\frac{b}{100a}\,. \tag{25-2}$$

$$c=\frac{b}{a}\left[2.02-\log_e\frac{b}{100}-.01\right]. \tag{25-3}$$

Substituting the value of c given by equation (25-3) in equation (23-4) and simplifying, we have

$$t=\frac{u}{a}+\frac{b}{a}\left[\log_e u-\log_e .01b+2.01\right]. \tag{25-4}$$

Equation (25-4) expresses the time for all positions of the *projectile in the bore,* where u represents the travel, t the corresponding time, and a and b the parameters of the hyperbola determined from equations (13) and (14).

To determine the time at which the projectile reaches the muzzle from equation (25–4), where the time is represented by t_1, and the travel to the muzzle by u_1, we have

$$t_1 = \frac{u_1}{a} + \frac{b}{a}\left[\log_e u_1 - \log_e \frac{b}{100} + 2.01\right]. \qquad (25\text{–}5)$$

From equation (12) the velocity-space curve of the projectiie may be determined. This curve is represented by Curve No. 1, Fig. 15, and from equations (12) and (25–4) the velocity-time curve of the projectile may be determined up to the time the projectile leaves the muzzle (see Curve No. 2, Fig. 15).

Velocity of free recoil.—Function of time.—Curve No. 2, Fig. 15, also represents the velocity of free recoil of the gun to a reduced scale. Curve No. 3 of Fig. 15 coinciding exactly with Curve No. 2 of Fig. 15, the ordinates of Curve No. 3 represent lower velocities on account of the greater mass. The ratio of the two scales are inversely proportional to the mass of the gun and the masses of the projectile and half the powder charge.

As stated before, sufficient pressure exists in the bore for a short time after the shell leaves the muzzle to further increase the energy of recoil of the gun. To determine the time *after the projectile leaves the muzzle,* it is assumed that the reaction on the gun falls off proportionally to the time, that is,

$$P_b = P_{b_1} - K(t - t_1), \qquad (26)$$

where P_b is the total reaction of the powder gases on the recoiling parts, at any time between t_1 and t_3, and P_{b_1} is the reaction at the time t_1 when the projectile leaves the muzzle—the value of P_{b_1} in equation (26) being determined from the following equation:

$$P_{b_1} = \frac{1.12a^2bpu_1}{g(b+u_1)^3}. \qquad (26\text{–}1)$$

NOTE.—Equation (26-1) is derived from Le Duc's formula for the determination of the pressure curve in the bore, where

P_{b_1} is the total pressure in lbs. in the bore when the projectile is at the muzzle.
u_1 is the travel of projectile to muzzle in feet.
p is the weight of the projectile in lbs.
a and b are parameters determined from equations (13) and (14).

K is a constant to be determined. From (26)

$$K = \frac{P_{b_1} - P_b}{(t - t_1)}. \qquad (26\text{–}2)$$

Substituting in this equation the time t_3 that the powder gases cease to act, we have

$$K=\frac{P_{b_1}}{t_3-t_1} \tag{27}$$

since P_b is zero when $t=t_3$.

Substituting the value of K from equation (27) in (26), we have

$$P_b=P_{b_1}-\frac{P_{b_1}}{t_3-t_1}(t-t_1). \tag{28}$$

From equation (28), the effect of the powder gases can be determined for any time after the projectile leaves the muzzle.

The momentum imparted to the recoiling parts by the powder gases during an increment of time dt after the projectile leaves the muzzle is

$$M_r dV=P_b dt, \tag{29}$$

where M_r is the mass of the recoiling parts.

Substituting the value of P_b equation (28) in equation (29) and transposing,

$$\int_{V_{f1}}^{V_f} dV=\int_{t_1}^{t}\frac{P_{b_1}dt}{M_r}-\frac{P_{b_1}tdt}{M_r(t_3-t_1)} \tag{29-1}$$

In the above equation, V_{f_1} is the velocity of free recoil at the time (t_1) when the projectile leaves the muzzle, obtained from equation (18), and V_{f3} is the maximum velocity of free recoil at the time (t_3) when the gases cease to act [obtained from equation (21)].

Integrating (29–1) between the limits of V_f and V_{f1} and the corresponding time t and t_1, we may determine the velocity of free recoil for any time (t) between t_1 and t_3.

$$\Big[V\Big]_{V_{f1}}^{V_f}=\Big[\frac{P_{b_1}t}{M_r}-\frac{P_{b_1}t^2}{2M_r(t_3-t_1)}\Big]_{t_1}^{t},$$

$$V_f-V_{f_1}=\frac{P_{b_1}(t-t_1)}{M_r}-\frac{P_{b_1}(t-t_1)^2}{2M_r(t_3-t_1)}. \tag{29-2}$$

Transposing and simplifying,

$$V_f=V_{f_1}+\frac{P_{b_1}(t-t_1)}{M_r}\left[1-\frac{(t-t_1)}{2(t_3-t_1)}\right]. \tag{29-3}$$

Substituting in equation (29–3) the value of t_3 for t, and its corresponding velocity V_{f3} for V_f, we have

$$V_{f3}=V_{f1}+\frac{P_{b_1}(t_3-t_1)}{M_r}\left[1-\frac{(t_3-t_1)}{2(t_3-t_1)}\right]. \tag{29-4}$$

Simplifying,

$$V_{f3}=V_{f1}+P_{b1}\frac{(t_3-t_1)}{2M_r}. \qquad (29\text{–}5)$$

From which,

$$t_3=t_1+\frac{2M_r(V_{f3}-V_{f1})}{P_{b1}}, \qquad (29\text{–}6)$$

where t_3 is the time when the gases cease to act.

The value P_{b_1} in equation (29–6) may be obtained from equation (26–1).

The curve of velocity of free recoil of the recoiling parts as a function of time, while the projectile is in the bore, may be determined from equation (12) by multiplying the velocity V_p of the projectile in the bore for any position of travel u by the ratio $\frac{W_r}{p+.5\varpi}$ or

$$V_f=\frac{au}{b+u}\times\frac{W_r}{p+.5\varpi}. \qquad (30)$$

The time for any position u of travel of projectile in the bore may be determined from equation (25–4).

The velocity of free recoil of the recoiling parts as a function of time after the projectile leaves the bore may be determined from equation (29–3). (See Curve No. 1, Fig. 16.)

130. Velocities of retarded recoil.—Function of time.—We have, so far, dealt only with the *velocity and time of free recoil.*

After the time t_3, when the free velocity of recoil attains its maximum value V_{f3}, the gun will continue to recoil indefinitely at the velocity V_{f3} if no restraining force is applied, in which case, the curve beyond this point would continue parallel to the axis ot_4, as shown in Fig. 16.

In practice, however, the velocities of free recoil are never reached, since they are continuously reduced under the action of the restraining forces, until the gun is brought to rest at the end of recoil. The restraining forces consist of the hydraulic brake force, the counter-recoil forces, friction, etc. The sum of these forces is the total resistance to recoil R_r, which must be offered to the recoil of the gun to bring it to rest in the required distance.

Since the total resistance to recoil is constant, the retardation will be constant and we may represent the curve of retardation by

a straight line drawn from the origin of motion so that the retardation (negative acceleration) will be

$$a = \frac{dv}{dt}, \tag{31}$$

the ordinates of the line representing negative velocities and the abscissæ corresponding times. (See Curve No. 2, Fig. 16.)

NOTE.—Since the ordinates of the line oC represent negative velocities, the line properly belongs below the axis. For convenience, however, the line is drawn above the axis as shown in Fig. 16.

Since the resistance R_r is constant, the retardation is constant, and we may write

$$R_r = aM_r, \tag{31-1}$$

that is, the retardation is the product of retardation and mass of the recoiling parts, from which

$$a = \frac{R_r}{M_r}. \tag{31-2}$$

The tangent of the angle t_4oC is equal to $-a$ or to $-\frac{dv}{dt}$.

The length of recoil of the mount, having been previously determined by practical considerations of the design, the problem is to determine the value of the total resistance R_r that will check the recoil of the gun in the required distance.

We will proceed to the determination of the resistance R_r in the following manner:

Curve No. 1, Fig. 16, represents the velocity of free recoil, function of time.

We have seen that the tangent to the curve at any point represents the acceleration at that point. We have also seen that the negative velocities due to the constant resistance R_r can be represented by the straight line oC, Fig. 16.

It is obvious that the maximum negative velocity due to the resistance must equal the maximum velocity of free recoil, since at the end of recoil

$$V_{f_3} - V_n \text{ (max.)} = 0, \tag{32}$$

where V_n is the negative velocity due to the retardation and V_n

(max.) is the maximum value at the end of recoil obtained from the expression

$$V_n(\text{max.}) = -at_4 \qquad (33)$$

where t_4 is the time of retarded recoil.

From equations (32) and (33), we may write

$$V_{f3} = -at_4, \qquad (33\text{–}1)$$

and from equation (33–1) and the value of $-a = \frac{R_r}{M_r}$. From equation (31–2), we have

$$V_{f3} = \frac{R_r}{M_r} t_4, \qquad (34)$$

from which

$$R_r = \frac{V_{f3} M_r}{t_4}. \qquad (35)$$

Since M_r is known and V_{f3} can be determined from equation (21), the value of the resistance R_r may be determined if the time of retarded recoil t_4 is known.

It is obvious that the velocity of retarded recoil (V_r) at any time is the difference between the velocity of free recoil and the negative velocity resulting from the retardation force at the corresponding time, or

$$V_r = V_{f3} - V_n. \qquad (36)$$

From equation (36) the ordinates of the curve of retarded recoil may be obtained (see Curve No. 3, Fig. 16) if the values of V_n are known. The values can easily be determined after the value of R_r is determined and the slope of the retardation line oC ascertained.

Velocity of retarded recoil.—Function of space.—Since an increment of space is equal to the time increment of velocity, we may write

$$dS_r = V_r dt, \qquad (37)$$

from which

$$S_r = \int V_r dt, \qquad (37\text{–}1)$$

where S_r is the length of retarded recoil corresponding to the velocity V_r.

From equation (37–1) it will be seen that the area under the curve of retarded velocities (Curve No. 3, Fig. 16), between the

origin and the ordinate corresponding to the velocity V_r, will represent the length of recoil corresponding to the velocity represented by the ordinate, and the total area under the whole curve will be the length of recoil S_{r4}.

The area under the curve of velocities of free recoil (Curve No. 1, Fig. 16) will, for the same reason, represent the distance traveled in free recoil. The area under the curve from the origin to point V_{f3} will represent the distance traveled in free recoil S_{f3}.

From Fig. 16, it will be seen that the area under the curve of velocities of free recoil (Curve No. 1, Fig. 16) includes all the values of free recoil up to time t_4. The area under the triangle t_4oC can be indicated by $\frac{V_{f3}t_4}{2}$, which is the reduction of travel of the recoiling parts due to the constant retarding force R_r.

Since the area under the curve of retarded recoil is S_{r4}, we may write for the length of recoil

$$S_{r4}=S_{f3}+V_{f3}(t_4-t_3)-\frac{V_{f3}t_4}{2},$$

simplifying

$$S_{r4}=S_{f3}+\frac{V_{f3}t_4}{2}-V_{f3}t_3, \tag{38}$$

from which

$$t_4=\frac{2(S_{r4}-S_{f3}+V_{f3}t_3)}{V_{f3}}. \tag{39}$$

Substituting the value of t_4, equation (39) in equation (35), we have for the value of R_r,

$$R_r=\frac{M_rV^2_{f3}}{2(S_{r4}+V_{f3}t_3-S_{f3})}. \tag{40}$$

V_{f3} in the above equation is the maximum velocity of free recoil determined from equation (21); S_{r4} is the length of recoil in feet; t_3 is the time the gases cease to act, determined from equation (29-6); and S_{f3} is the space recoiled by the recoiling parts when the gases cease to act. S_{f3} may be determined in the following manner:

Since $ds=V_fdt$

$$\int_{s_{f1}}^{s_f} ds=\int_{t_1}^{t} V_fdt, \tag{41}$$

and from (29-1)

$$V_f=\frac{P_{b1}t}{M_r}-\frac{P_{b1}t^2}{2M_r(t_3-t_1)}+V_{f1}. \tag{42}$$

Substituting equation (42) in equation (41),

$$\int_{S_{f1}}^{S_f} ds = \int_{t_1}^{t} \frac{P_{b_1} t\,dt}{M_r} - \frac{P_{b_1} t^2 dt}{2M_r(t_3 - t_1)} + V_{f_1} dt. \qquad (43)$$

Integrating and transposing,

$$S_f = S_{f_1} + \frac{P_{b_1}(t-t_1)^2}{2M_r} - \frac{P_{b_1}(t-t_1)^3}{6M_r(t_3-t_1)} + V_{f_1}(t-t_1). \quad (43\text{–}1)$$

S_f being the space of free recoil corresponding to time t between the values S_{f_1} and S_{f_3}.

Substituting S_{f_3} for S_f and t_3 for t in equation (43–1), and simplifying,

$$S_{f_3} = S_{f_1} + (t_3 - t_1)\left[V_{f_1} + \frac{P_{b_1}(t_3 - t_1)}{3M_r}\right]. \qquad (43\text{–}2)$$

With the value of S_{f_3} given by equation (43–2), the value of the constant resistance R_r given in equation (40) may be determined.

Having the value of R_r, the slope of the line oC may be determined from the relation $-a = \frac{R_r}{M_r}$ where $\frac{R_r}{M_r}$ is the tangent of the angle of the slope.

The curve for velocity of retarded recoil, function of space, can be computed in the following manner:

Since the retarding force R_r is constant, the retarded velocity V_r at any point will be

$$V_r = V_f - V_n \qquad (44)$$

where V_n is the reduction in velocity due to R_r.

Also $V_n \doteq -at$, but since $-a = \frac{R_r}{M_r}$ $V_n = \frac{R_r t}{M_r}$, from which

$$V_r = V_f - \frac{R_r t}{M_r}. \qquad (44\text{–}1)$$

Equation (44–1) may be solved for the various values of time and the space (S_r) traveled for corresponding times computed as follows:

Let S_n represent the reduction in space traveled at any time due to R_r. [Where S_n represents the space traveled by the recoiling parts at any time t, starting from zero velocity with no forces except R_r acting.]

Then

$$S_n = \tfrac{1}{2}at^2 = \tfrac{1}{2}\frac{R_r}{M_r}t^2. \tag{45}$$

Also

$$S_r = S_f - S_n. \tag{45-1}$$

From which, substituting $\frac{1}{2}\frac{R_r}{M_r}t^2$ for S_n,

$$S_r = S_f - \tfrac{1}{2}\frac{R_r}{M_r}t^2. \tag{45-2}$$

Equations (44–1) and (45–2) may be solved for the full recoil, but it is more convenient to use the following method after passing the point of maximum velocity of retarded recoil:

Since the inertia force is the only force acting to produce recoil after the maximum velocity of free recoil is attained, we may write

$$\frac{M_r V_r^2}{2} = R_r(S_{r_4} - S_r), \tag{46}$$

from which

$$V_r = \frac{2R_r(S_{r_4} - S_r)}{M_r}. \tag{46-1}$$

Point of maximum velocity of retarded recoil.—It is often necessary in the early stages of the design to know the maximum area of the throttling orifice in order to properly proportion the various parts of the recoil system. The maximum area of throttling orifice will coincide with the point of maximum velocity of retarded recoil, and the maximum area may easily be determined from equation (9) when the maximum velocity of retarded recoil has been determined. The point of maximum velocity of retarded recoil may be determined in the following manner:

For the point corresponding to the maximum velocity of retarded recoil, let t_2 represent the time, V_{f_2} the velocity of free recoil, S_{f_2} the space traveled in free recoil. At the point of maximum velocity of retarded recoil, P_b equals R_r, since at this point the tangent to the curve of velocity of retarded recoil is parallel to the X-axis and the accelerating and retarding forces are equal.

Substituting R_r for P_b in equation (28) and solving for $(t - t_1)$ at the point t_2, we have

$$(t_2 - t_1) = \frac{(P_{b_1} - R_r)(t_3 - t_1)}{P_{b_1}}; \tag{47}$$

transposing equation (47), we get

$$P_{b_1} = \frac{(P_{b_1} - R_r)(t_3 - t_1)}{t_2 - t_1}. \tag{47-1}$$

Substituting in equation (29–3) the value of P_{b_1} from equation (47–1), and writing t_2 for t and V_{f_2} for V_f, we get

$$V_{f_2}=V_{f_1}+\frac{(P_{b_1}-R_r)(t_3-t_1)(t_2-t_1)}{(t_2-t_1)M_r}\left[1-\frac{(t_2-t_1)}{2(t_3-t_1)}\right]. \quad (48)$$

Substituting value of t_2-t_1, from equation (47) in equation (48), we have

$$V_{f_2}=V_{f_1}+\frac{(P_{b_1}-R_r)(t_3-t_1)}{M_r}\left[1-\frac{(P_{b_1}-R_r)(t_3-t_1)}{2P_{b_1}(t_3-t_1)}\right], \quad (48\text{–}1)$$

$$V_{f_2}=V_{f_1}+\frac{(P_{b_1}-R_r)(t_3-t_1)}{M_r}\left[1-\frac{(P_{b_1}-R_r)}{2P_{b_1}}\right], \quad (48\text{–}2)$$

V_{f_2} being the point in the velocity of free recoil curve corresponding to the maximum velocity of retarded recoil.

Substituting the value of (t_2-t_1) from equation (47) in equation (43–1), giving S_f its value S_{f_2}, we get

$$S_{f_2}=S_{f_1}+V_{f_1}\frac{(P_{b_1}-R_r)(t_3-t_1)}{P_{b_1}}+\frac{P_{b_1}(P_{b_1}-R_r)^2(t_3-t_1)^2}{2M_rP_{b_1}}$$
$$+\frac{P_{b_1}(P_{b_1}-R_r)^3(t_3-t_1)^3}{6M_rP_{b_1}^3(t_3-t_1)^2}, \quad (49)$$

or

$$S_{f_2}=S_{f_1}+\frac{(P_{b_1}-R_r)(t_3-t_1)}{P_{b_1}}V_{f_1}+\frac{(P_{b_1}-R_r)(t_3-t_1)}{2M_r}$$
$$-\frac{(P_{b_1}-R_r)^2(t_3-t_1)}{6M_rP_{b_1}}. \quad (49\text{–}1)$$

S_{f_2} being the space traveled in recoil when the maximum velocity of retarded recoil occurs.

131. Determination of area of throttling orifice.—Having determined the curve of velocities of retarded recoil, we may determine the area of the throttling orifice at all points of the recoil to give the required hydraulic resistance from equation (9).

The constant resistance R_r includes the hydraulic brake resistance, the resistance offered by the counter-recoil system, frictional resistances, etc. Gravity also exerts a varying effect, depending on the angle of elevation of the gun. The proper allowance must be made for the forces mentioned and the proper adjustments made in the value of the hydraulic brake resistance in order that the total resistance, *i. e.*, the algebraic sum of the resistances, shall be constant for all points of the recoil.

The equation of forces may be written as follows:

$$R_r = W_r f \cos\psi - W_r \sin\psi + R_h + R_s + R_p. \qquad (50)$$

Where

W_r = The recoiling weight in pounds.
f = Coefficient of friction.
ψ = Angle of elevation.
R_s = Counter-recoil force in pounds at any point.
R_h = Hydraulic brake resistance at any point.
R_p = Packing gland resistance.

From equation (50) the value of the hydraulic brake resistance at any point may be computed, or

$$R_h = R_r - W_r f \cos\psi + W_r \sin\psi - R_s - R_p. \qquad (51)$$

Substituting the proper value of R_h and V_r for each point of the recoil in equation (9), we have for the area of the orifice at any point

$$a_r^2 = \frac{C^2 Y A_r^3 V_r^2}{2gR_h}. \qquad (52)$$

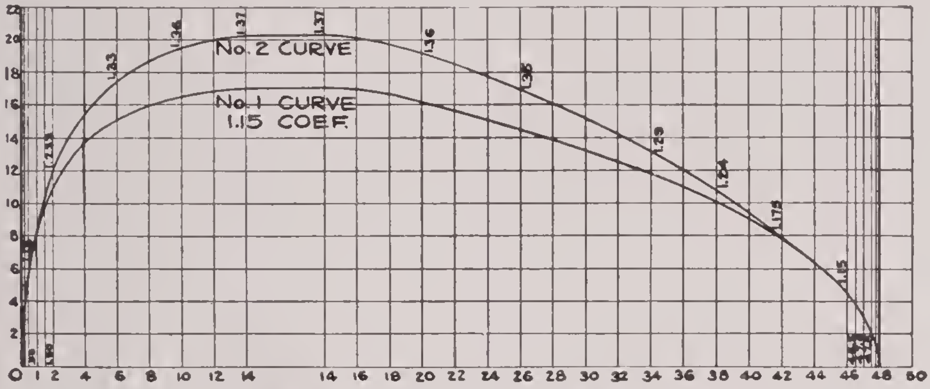
Where a_r is the area of the orifice in square feet.
Y is the weight per cubic foot of the recoil fluid.
V_r is the velocity of retarded recoil in feet per second.
g is the acceleration of gravity 32.16.
R_h is the hydraulic brake resistance in pounds for any point corresponding to the velocity V_r.
C is a variable coefficient of contraction which varies between the limits of 1.15 to 1.37 for throttling rods [such as are used in major caliber mounts], and between 1.12 to 1.20 for grooves [such as are used in minor caliber mounts].

It should be noted in the case where n orifices are used, the area for each orifice is equal to $\frac{A_r}{n}$, where a_r is the total area of orifice determined from equation (52).

Fig. 17 shows the curves for recoil areas for a throttling rod type of recoil system. The required area of orifice in square inches for each point of the recoil is represented by the ordinates of the curve for each point of the recoil. (See Curve No. 2, Fig. 17.) Curve No. 1, Fig. 17, shows the curve of areas where the

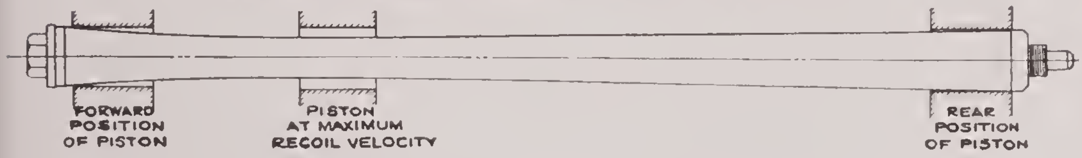
factor C has the constant value 1.15. Curve No. 2, Fig. 17, is laid out with C equal to 1.15 at the origin and increasing to 1.37 at the maximum ordinate. It will be noted that there is a space of about $2\frac{1}{2}$ inches where the maximum ordinate remains constant. This space is equal to the length of the piston, and represents the point at which the throttling edge of the orifice shifts from the forward edge of the piston to the rear edge.

From Curve No. 2, Fig. 17, the actual diameters of the recoil rod at the various positions of recoil are determined.



NO.	DESIGNATION OF CURVES	VERTICAL SCALE	HORIZONTAL SCALE
1	CURVE ORDINATES = 1.15 X COMPUTED AREA	1 DIVISION = 2 SQ.IN.	1 DIVISION = 2".0
2	CURVE ORDINATES = K X COMPUTED AREA	1 DIVISION = 2 SQ.IN.	1 DIVISION = 2".0

NOTE: K VARIES FROM 1.15 TO 1.37 TO SUIT ORIFICE AS SHOWN.



NOTE: THE ABOVE CURVES WERE LAID DOWN FOR A 16-INCH MOUNT. THE CURVES WILL VARY TO SUIT EACH TYPE AND CALIBER OF MOUNT.

FIG. 17.

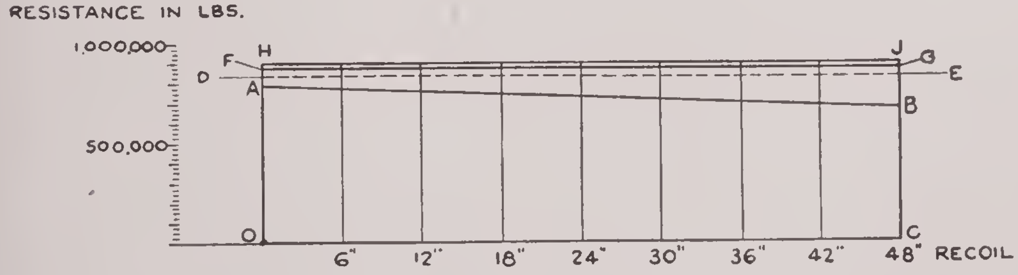


FIG. 18.

132. Work of resistance.—The work of resistance to recoil and the manner in which the values of the elements of resistance vary throughout the length of recoil may best be represented graphically by the work diagram shown in Fig. 18. The line OC in the

diagram represents the length of recoil; the constant retarding force which is the total resistance R_r offered to recoil is represented by the ordinate OH.

The value of the resistance R_r is a maximum when the gun is fired at the maximum angle of elevation, since the value of $W_r \sin \psi$, equation (50), is maximum at that angle. On this account, the value of the resistance R_r is computed from equation (50) for the maximum angle of elevation. OH in Fig. 18 represents the value of R_r thus computed.

Referring to Fig. 18, the area of the figure $ODEC$ represents the work of recoil with the gun fired horizontal; the area $DHJE$ represents the work of gravity at the maximum angle of elevation, where the ordinate $DH=EJ$ represents the value $W_r \sin \psi$ (equation (50)). The area $FHJG$ represents the work of resistance contributed by the friction forces $W_r f \cos \psi$ and R_p; the area $AFGB$ represents the work of resistance offered by the counter-recoil system; and the area $OABC$ represents the work of resistance of the hydraulic brake, R_h.

It will be observed that the values of the counter-recoil force (R_s) and of the hydraulic brake force (R_h) vary in magnitude throughout the length of recoil.

133. Hydraulic brake force.—The value of (R_h) for each point of the recoil can be determined after the proper deductions have been made for all the other forces at corresponding points; or from equation (51)

$$R_h = R_r + W_r(\sin \psi - f \cos \psi) - R_s - R_p, \tag{53}$$

where R_h varies for each point of recoil.

134. Counter-recoil force.—The function of the counter-recoil system is to return the gun to battery after recoil. The force necessary to accomplish this may be determined from the following equation:

$$R_{s_1} = W_r(f \cos \psi + \sin \psi) + R_p, \tag{54}$$

where the values have the same significance as in equation (50), and R_{s_1} is the value for R_s at the beginning of recoil. The value of the coefficient f is usually estimated to be 25 per cent in order to take care of all conditions of lubrication that may arise aboard ship. The value of the packing gland resistance can be approximated from a study of the mount design, and may be considerable for major caliber mounts.

Springs may be satisfactorily employed for returning the gun to battery in the case of minor caliber mounts, and until recently were used for the same purpose for major caliber mounts, where the maximum angle of elevation did not exceed 15°. On account, however, of the recent large increase in caliber of major caliber guns, together with the large increase in the length of recoil and the maximum angle of elevation of these guns, the use of springs for returning the major caliber guns to battery is not practicable, and compressed air is used on the later mounts.

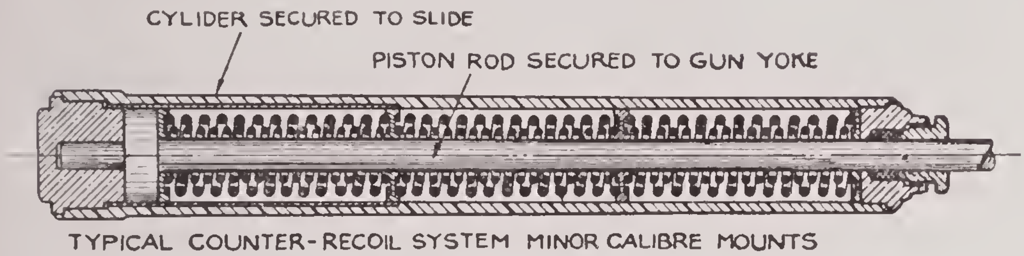


FIG. 19.

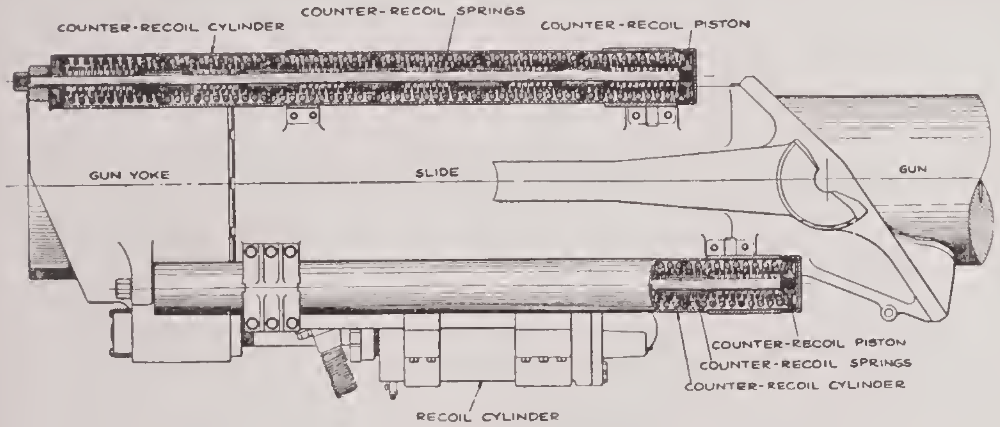


FIG. 20.—TYPICAL COUNTER-RECOIL SYSTEM FOR TURRET MOUNTS.

Fig. 19 shows a typical application of springs to a minor caliber mount; Fig. 20 shows a spring installation as applied to turret mounts. The springs are assembled with sufficient initial compression to bring the gun to battery against the forces of gravity and friction as determined from equation (54) for the maximum angle of elevation. As the gun recoils, the springs are further compressed, and, as a result, the spring resistance R_s constantly increases from the beginning to the end of recoil, so that the value of R_s at the end of recoil is usually 100 per cent greater than its

value (R_{s_1}) at the beginning of recoil. The proper allowance may easily be made for the variation of the magnitude of the force R_s for each point of the recoil. In Fig. 11, the ordinate AF represents the value R_s, at the beginning of recoil, and the ordinate BG the value of R_s at the end of recoil. Where springs are used, AB is a straight line, since the spring force varies directly as the amount of compression of the spring.

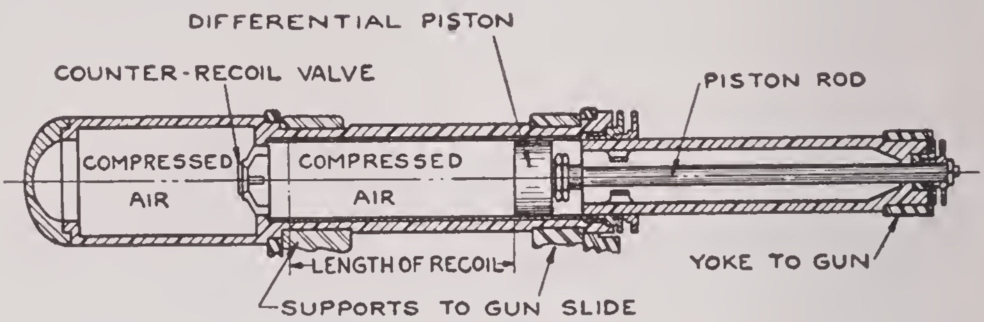


FIG. 21.—TYPICAL PNEUMATIC COUNTER-RECOIL SYSTEM MAJOR-CALIBER MOUNTS.

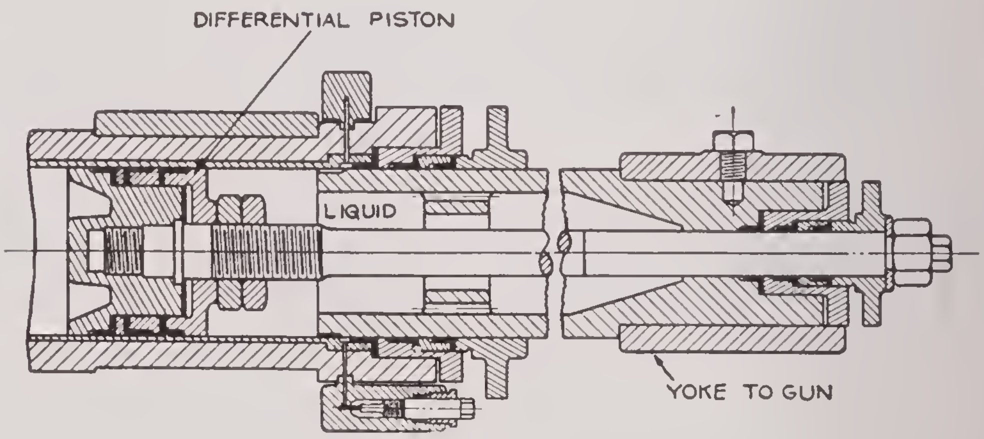


FIG. 22.

In the case of compressed air, the initial force R_{s_1} is derived from the compression of the air. Figs. 21 and 22 represent a typical compressed air (pneumatic) counter-recoil system as applied to major caliber mounts. The air is compressed to from 300 to 1600 pounds per square inch initial pressure, and this pressure is held practically indefinitely without leakage by the use of special packings. During recoil, the pressure is increased from 40 to 50 per cent above the initial pressure. In the case of compressed air, line AB, Fig. 18, will not be a straight line.

Since the time interval of recoil is small, we may without great error assume that compression takes place without loss of heat, and that the compression is adiabatic; in which case the pressure at any point may be determined from the following equation:

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^K \tag{55}$$

where P_1 is the initial pressure; V_1 is the initial volume; P_2 is the final pressure; V_2 is the final volume; and K is a constant 1.41.

Having determined the value of the pressure for each point of the recoil, the value of R_s and R_2 for each point may be determined.

135. Forces acting on the gun during recoil.—It is important that the jump of the gun between the time the gun pointer "wills to fire" and the time the projectile leaves the gun shall be

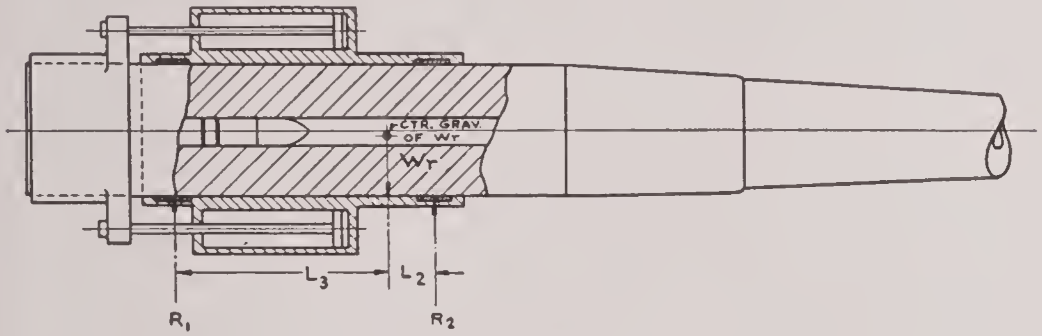


FIG. 23.

the least possible amount. The reasons for this are obvious. On this account, it is desirable and necessary that the forces acting on the gun, including those due to the powder gases and the forces resisting recoil, be so disposed that the gun will not be lifted from its bearing in the bottom of the slide until after the projectile leaves the gun, and that the only appreciable movement of the gun before this time will be in the direction of the axis.

Before the gun is fired, the forces acting are the weight of the recoiling parts W_r and the reactions R_1 and R_2, Fig. 23. Under the action of these forces, the gun rests in the bottom of the slide which supports it.

When the gun is fired and the powder gases begin to act, the forces of inertia $\frac{W_r}{g}a$, hydraulic brake resistance R_h, counter-recoil resistance R_s, friction, etc., begin to exert their effect. It is

important that the initial position of the gun, immediately before firing, be disturbed as little as possible under the action of these forces until the projectile leaves the muzzle. Under no condition should the effect of these forces be to lift the gun from its bearing in the bottom of the slide before the projectile reaches the muzzle. Whether such a condition exists in any design may be determined by writing the equation of forces and solving for the reactions R_1 and R_2 of Fig. 24. If these reactions in any case prove to be negative, the condition may be regarded as unsatisfactory.

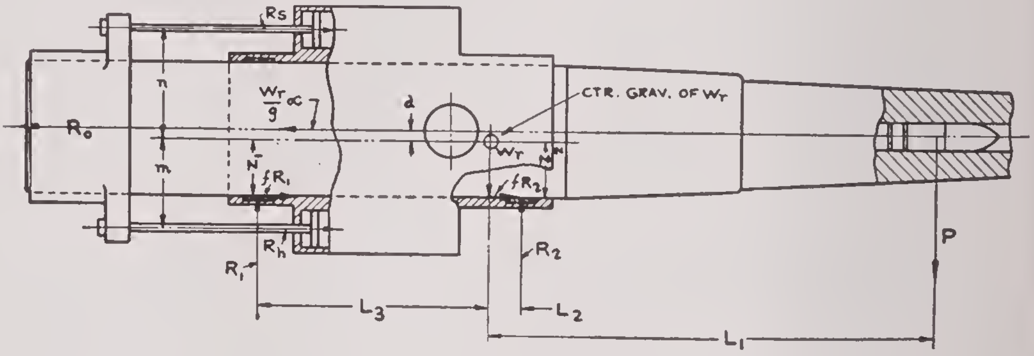


FIG. 24.

Writing these equations, we have

$$R_1+R_2=W_r, \tag{56}$$

or

$$R_1=W_r-R_2, \tag{56-1}$$

and

$$R_2=W_r-R_1. \tag{56-2}$$

Taking moments about the center of gravity of the recoiling weights, W_r, we have

$$R_1L_3=R_hM+\frac{W_rad}{g}+fR_1z_1+fR_2z_2+R_2L_2-R_sn-PL_1. \tag{56-3}$$

Substituting in equation (56–3) for R_2 its value from equation (56–2), we get

$$R_1L_3=R_hm+\frac{W_rad}{g}+fR_1z_1+fz_2(W_r-R_1)+ L_2(W_r-R_1)-R_sn-PL_1. \tag{56-4}$$

Simplifying, we have

$$R_1=\frac{R_hm+\frac{W_rad}{g}+fW_rz_2+W_rL_2-R_sn-PL_1}{L_3-fz_1+fz_2+L_2}. \tag{56-5}$$

Substituting in equation (56–5) for R_1 its value from equation (56–1) and transposing, we have

$$R_2 = W_r - \frac{R_h m + \frac{W_r a d}{g} + f W_r z_2 + W_r L_2 - R_s n - P L_1}{L_3 - f z_1 + f z_2 + L_2}. \quad (56\text{–}6)$$

To insure a steady mounting and to reduce the jump of the gun in the slide to a minimum, it is desirable to keep the distance [*d*, Fig. 24] of the center of gravity of the recoiling weights below the axis of the gun as small as possible. On the later design of mounts, the center of gravity of recoiling parts is located approximately on the axis of the gun. For the same reason, the mount should be designed so that the counter-recoil cylinders are located on the side of the gun opposite to the hydraulic brake cylinder (recoil cylinder).

136. Pneumatic counter-recoil system.—A pneumatic counter-recoil cylinder as applied to major caliber mounts is illustrated in Fig. 21. Three such cylinders are mounted on each side. The cylinders are secured to the gun slide in much the same way as has been the practice heretofore in the case of spring cylinders. The piston rods are attached to a yoke that recoils with the gun. The piston rod, piston, and the liquid around the piston rod move together during recoil. The liquid and piston arrangement shown is for the purpose of lubricating the cupped leather packings and to facilitate the packing of the air at the high pressures use. The initial pressure of the air in the particular mount illustrated is 1200 pounds per square inch. This pressure is increased to 2100 pounds at the extreme recoil position. The counter-recoil valve shown in the figure opens during recoil and permits the air in the forward section of the cylinder to pass into the rear section of the cylinder, the valve closing at the end of recoil. A small orifice in the valve connects the forward and rear portions of the cylinder and the air flows from the rear portion of the cylinder to the forward portion until the pressures in the two portions of the cylinder are equalized. The function of this valve is to regulate the flow of air from the rear to the forward chamber during counter-recoil by throttling, so that the return of the gun to battery will not be too violent. The final movement of the gun to battery is checked in the usual manner by the counter-recoil plunger and dash pot which is part of the recoil system.

The success of the pneumatic counter-recoil system depends on the reliability of the packing. It has been found by actual experience that if the packing is properly designed, air at high pressure can be retained for long periods with no diminution in pressure. Fig. 22 shows to larger scale the feature of the packing which is a part of the system shown to smaller scale in Fig. 21.

Two practical difficulties are experienced in packing air at high pressures. First, it is difficult to get castings of sufficient density and homogeneity to prevent the leakage of the air through the pores of the metal. The second difficulty is that of packing air under high pressures owing to the tendency of cupped packing and other forms of packing to dry out and permit the air to escape. The first difficulty can be overcome to a great extent by the use of forged material instead of castings for all parts inclosing the air. The second difficulty is overcome by introducing a liquid chamber between the air chamber and the atmosphere, as shown in Fig. 22. By means of the differential piston shown, the liquid is under a higher unit pressure than the air, which it packs, so that the liquid tends to escape through the differential piston to the air chamber or through the piston rod packing to the atmosphere. Whereas great difficulty is experienced in packing air by the usual methods, no great difficulty is experienced in packing liquid at the same or increased pressures since the liquid keeps the packing moist and the surfaces with which it comes in contact well lubricated. Special care must be exercised, however, in the selection of the material for the cup packing, and also of the material for the liquid, in order that galvanic action will not be set up between the ferrous and non-ferrous parts with which it comes in contact.

The difference in unit pressure between the liquid and air is determined by the proportions of the differential piston. The area of the surface exposed to the air is greater than the area of the surface exposed to the liquid by an amount equivalent to the area of the piston rod.

During recoil, the liquid in the liquid chamber lubricates the surfaces of the cylinder and piston rod so that it is necessary to replenish the liquid in this chamber from time to time as the mount is used. The piston rod of the differential system which is

exposed to the atmosphere serves as an indicator from which can be determined the time when it is necessary to replenish the liquid.

137. Stresses in deck structure due to firing.—The bolts securing the mount to the deck and the deck structure itself must be capable of withstanding the weight of the gun and mount and the turning moment produced by the reaction of the slide trunnions in the trunnion seats of the carriage.

The forces acting on the deck structure when the mount is fired are shown in Fig. 25.

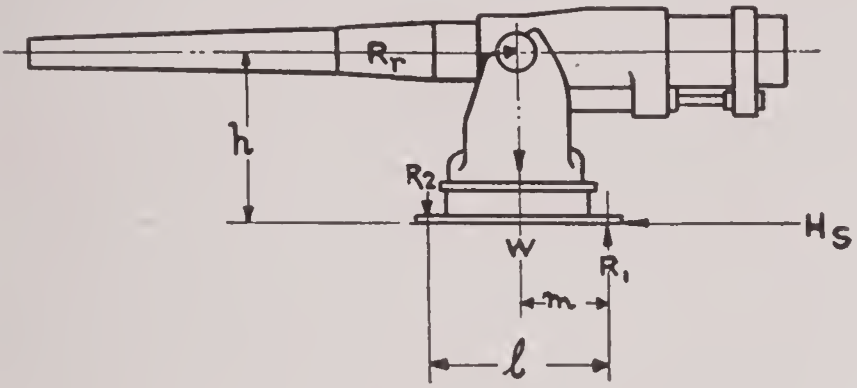


FIG. 25.

These forces, R_1, R_2, and H_s may be determined as follows:

For equilibrium, the summation of all horizontal forces is equal to zero, or

$$R_r - H_s = 0. \tag{57}$$

Taking moments about R_1 we get

$$R_r h - W m - R_2 l = 0, \tag{57-1}$$

or

$$R_2 = \frac{R_r h - W m}{l}. \tag{57-2}$$

Taking moments about R_2, we get

$$R_r h + W(l - m) - R_1 l = 0, \tag{57-3}$$

or

$$R_1 = \frac{R_r h + W(l - m)}{l}. \tag{57-4}$$

Equations (57-2) and (57-4) give the value of the reactions at the beginning of recoil. The value of the reactions with the

gun at extreme recoil may be determined by making the proper allowance for the movement of the weight of the recoiling parts through the distance of recoil.

138. Standard trunnion pressure formula.—In order to have a uniform, simple formula available for comparing the stresses set up by various guns and mountings when extemporizing new armament for vessels, or in the preliminary stages of the mount design where it is necessary to form some idea of the forces acting in advance of the completion of the design, the Bureau of Ordnance has adopted certain formulas for computing the constant resistance force R_r and the resultant trunnion pressure due to this force and the weight of the oscillating weights.

It has been found that sufficiently accurate results for the purposes above mentioned can be obtained if we assume the velocity of free recoil curve, function of time (Curve No. 1, Fig. 9), is a parabola. With this assumption, it is possible to derive a comparatively simple equation for the constant retarding force, and the time of retarded recoil t_4.

Proceeding on the basis of the above assumption, we may write for the velocity of free recoil at any time

$$V_f=\sqrt{2pt},$$

where $2p$ is the latus-rectum of the parabola and V_f and t have the same significance as in the previous discussion.

As previously shown, the value of R_r may be expressed as follows:

$$R_r=\frac{W_r V_{f3}}{g t_4}, \tag{35}$$

where R_r is the constant resistance necessary to check the recoil in the distance S_{r4}, V_{f3} is the maximum velocity of free recoil, and t_4 is the time of retarded recoil.

V_{f3} may be obtained from the equation

$$V_{f3}=\frac{(PV_p+4700\bar{w})}{W_r}. \tag{21}$$

Assuming the velocity of free recoil, function of time, to be a parabola, and referring to Fig. 9, the area under Curve No. 1

from the origin to the point of maximum velocity of free recoil (V_{f3}) will be

$$\tfrac{2}{3}V_{f3}t_3.^*$$

Remembering that the area under the curve of velocity of retarded recoil is the length of recoil S_{r4}, we may write (see Fig. 9)

$$S_{r4}=V_{f3}(t_4-t_3)+\tfrac{2}{3}V_{f3}t_3-\frac{Vf_3t_4}{2}.$$

From which

$$t_4=\frac{2\left(S_{r4}+\dfrac{V_{f3}t_3}{3}\right)}{V_{f3}}. \qquad (58)$$

By substituting the value of t_4 equation (58) in equation (35), we may obtain the value of the constant resistance R_r. It is customary to increase the value of R_r obtained from equation (35) by 10 per cent to 25 per cent to cover irregularities that may be expected due to the semi-empirical nature of the equation.

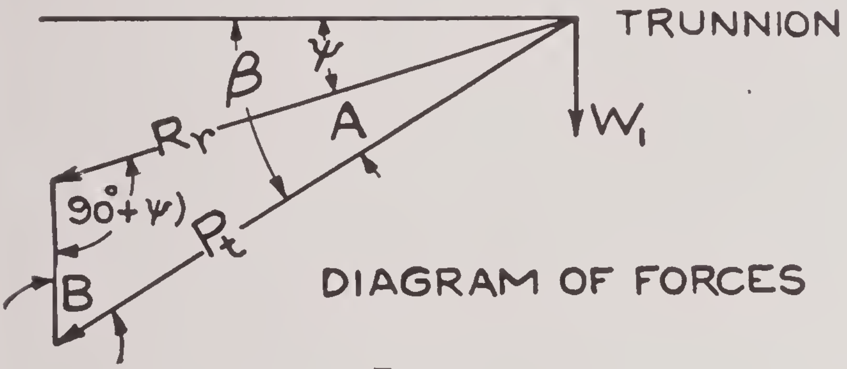


FIG. 25A.

The trunnion pressure R_t is the resultant of the constant resisting force R_r and the weight W_1 of the oscillating parts supported by the trunnions.

These two forces may be represented in magnitude and direction by the lines shown in Fig. 25a.

* The area under the curve at any point is

$$\text{area}=\int_{t_0}^{t}V_f dt.$$

Substituting for V_f its value $\sqrt{2pt}$ and integrating between the limits $t_0=0$ and $t=t_3$, we have

$$\text{area}=\sqrt{2p}\int_0^{t_3}t^{\frac{1}{2}}dt=\sqrt{2p}\times\tfrac{2}{3}[t^{\frac{3}{2}}]_0^{t_3}.$$

Substituting for $2p$ the value obtained by substituting V_{f3} for V_f and t_3 for t in equation $V_f=\sqrt{2pt}$, and simplifying,

$$\text{area}=\frac{V_{f3}}{\sqrt{t_3}}\times\tfrac{2}{3}[t^{\frac{3}{2}}]_0^{t_3}=\tfrac{2}{3}V_{f3}t_3.$$

Where ψ is the maximum angle of elevation and P_t the trunnion pressure corresponding to this angle.

Solving the triangle of forces, we have

$$P_t = W_1 \frac{\sin(90° + B)}{2240 \sin A}, \tag{59}$$

where P_t is in tons (2240 pounds) and A the angle obtained from the relation

$$\frac{\tan \frac{1}{2}(B - A)}{\tan \frac{1}{2}(90 - B)} = \frac{(R_r - W_1)}{(R_r + W_1)}. \tag{60}$$

Equations (58), (35), and (59) are regarded by the Bureau of Ordnance as standard formulas for computing trunnion pressures in all preliminary calculations. They are not sufficiently accurate, however, for computing throttling orifices, these being computed by the methods previously discussed.

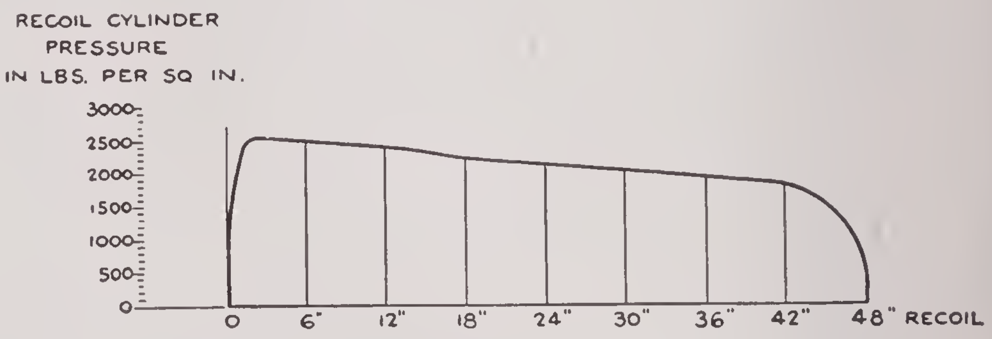


FIG. 26.

139. Test of recoil system at the proving ground.—When a new type of mount is proved at the Naval Proving Ground, it is the practice to take indicator cards showing the pressures in the recoil cylinders and the counter-recoil dash pots together with velocity of recoil cards.

140. Recoil cylinder pressure indicator cards.—An indicator similar to a steam engine indicator is attached to the recoil cylinder and the drum to which the indicator card is attached is connected by a cord to the gun yoke. The pressure occurring in the recoil cylinder during recoil is recorded on the indicator card, so that the pressure for each point of the recoil is shown. Fig. 26 shows a typical indicator card for a 16-inch mount.

141. Velocity of recoil curves.—The velocity of recoil is measured by means of an instrument known as the Siebert velocimeter, named after its inventor. A steel tape is attached to a part of the gun. The tape moves past a pointer attached to a tuning fork as the pointer vibrates in a direction transverse to the direction of movement of the tape. During recoil a line is traced by the pointer on the tape. The record made consists of a number of waves of varying lengths; the length depending on the speed of the tape. The rate of vibration of the tuning fork being known, the time of travel may be found by measuring the length of the waves and dividing by the known period of the tuning fork. In this manner, the velocity of recoil at all points may be determined and the velocity of recoil curve constructed from the data obtained.

CHAPTER V.

NAVAL RIFLED GUNS.

General Discussion—Definitions.

142. **A gun** is a mechanical device, consisting of a tube closed at one end at the moment of firing, capable of containing a projectile and a propelling charge, and of so controlling the explosion of the charge as to discharge the projectile with a high velocity.

143. **A mortar** is a short, heavy gun using a high angle of fire.

144. **A rifle** is a gun whose bore has cut on its surface a number of spiral *grooves,* into which the soft metal of the rotating band on the projectile is forced, thus imparting to the projectile a motion of rotation. The raised portions between the grooves are called *lands*. (See Plate I.)

145. **A cast gun** is one made by casting metal in a mold in the form of a gun, or approximately the form. Iron, bronze, and steel have been thus used. Cast guns are used in several foreign navies, but are used in our navy for drill guns only.

146. **A built-up gun** is any gun made up of different parts, the idea being to get an assemblage of parts best able to resist the pressures of the powder gas. The gun may be built up of different metals. The most usual forms are: (1) The built-up gun with initial pressure obtained by shrinkage, the exterior parts being heated to go over the interior parts; and (2) the "wire-wound" gun.

147. **A low-power gun** is any gun having a low muzzle velocity and a low pressure.

148. **A high-power gun** is any gun having a high muzzle velocity and a high pressure.

As the terms "low-power" and "high-power" are relative, no fixed velocity and pressure can be stated to distinguish between the two.

149. **The bore of a gun** is that part of the interior of the tube that is of uniform diameter from the "powder chamber" (origin of rifling) to the muzzle.

150. The chamber of a gun is the space allotted to the powder charge, and is that part of the interior of the tube between the "bore" and the face of the breech plug when closed. The "chamber" is made larger in diameter than the "bore" in order to reduce its length, and so give a greater length of travel for the projectile in the "bore." The ratio of the diameter of the "chamber" to the diameter of the "bore" is called *chambrage.*

151. The caliber of a gun is the diameter of a cylinder which touches the *highest* points of all the lands.

The word caliber is also used in connection with the length of the gun, meaning the length of the gun divided by the diameter of the bore. That is, it is the over all length of the gun from the breech face to the muzzle face expressed in the caliber of the gun as units. Thus a 50-caliber 12-inch B. L. R. is 50 calibers, that is 50 feet, in over all length, from the breech face to the muzzle face. An allowance is sometimes added for the breech-plug housing.

152. The gun metal thickest over the chamber.—This is the case because at the point over the seat of the powder charge the pressure of the powder gas is the greatest. The powder pressures gradually decreasing toward the muzzle, the strain on the gun becomes less, and hence the gun may taper forward.

153. Parts of a gun.—A gun as viewed from the outside has the following parts: *Breech, rear cylinder, slide cylinder, chase, muzzle.* (See Plate I.)

The *breech* is the rear end of the gun, while the *muzzle* is the front end, whence the projectile issues.

The *rear cylinder,* at the breech end of the gun, is that part over the chamber where the metal is thickest.

The *slide cylinder* is that part of a gun forward of the rear cylinder which fits in the slide and moves through it in recoil. It is fitted with a key that is contained in a keyway in the slide which prevents the gun from turning in the slide, restricting it to longitudinal motion only. This part of the gun is made truly cylindrical to fit snugly in the slide.

The *chase* is the sloping portion forward of the slide cylinder extending to the muzzle, whether in one taper or in stepped tapers caused by hoops.

The end of the chase forms a curve at the muzzle of increased diameter, forming what is known as the "bell muzzle." The metal

is increased at that point to give greater strength, to prevent enlargement of the bore due to high muzzle pressures.

The *trunnions* are two horizontal cylindrical projections at right angle to the axis of the bore of the gun, the purpose of which is to support the gun on the *carriage*. They are located at or near the center of gravity of the gun, and form the axis around which it moves in elevation. In the United States Navy it is customary to have the trunnions slightly towards the breech, thus making the gun " muzzle heavy " when empty, but balanced when loaded.

In cast guns the trunnions are in one with the gun. Built-up guns are made *trunnionless,* the gun being supported by the " slide " or " sleeve " within and through which the gun moves in recoil, the trunnions in this case being cast with the slide.

The trunnions rest in " seats " on the gun carriage.

The recoil is checked by hydraulic or pneumatic cylinders attached to or cast with the slide, the pistons of which are connected by their rods to a "yoke" around the rear cylinder of the gun. Sometimes this arrangement is reversed, the cylinders being attached to the gun and the pistons being held fixed. The slide is usually bushed with bronze or gun metal to prevent the steel of the gun from sliding on the steel of the slide. Heavy grease is used as a lubricant between the surfaces of the gun and slide.

154. Breech-loading rifles and **rapid-fire guns** were terms previously used to designate different types of guns. However, all modern naval guns are breech-loading, all are rifled, and all are more or less rapid-firing; hence the terms have been abandoned. Instead, thereof, the terms *bag guns* and *case guns* have been adopted.

155. Bag guns are guns that do not use metallic cases for the powder. A mushroom and gas-check pad are therefore required to prevent the powder gases, under the high pressures of explosion, from escaping to the rear around the plug.

156. Case guns are those in which a metallic powder case is used, this case preventing escape of gas to the rear, so that no mush-room and gas-check pad are required.

157. Field guns are of 3-inch caliber and are supplied with field carriages for use on shore.

158. **Boat guns** are supplied with mounts for use in small boats.

159. **Automatic guns** are those in which the force of explosion is used to eject the fired cartridge-case and load another cartridge. When ammunition is properly supplied, no force but pressure on the trigger is required for continuous fire.

160. **Semi-automatic guns** are those in which the force of explosion ejects the fired cartridge-case and leaves the breech so that it closes automatically when another cartridge is properly inserted.

161. **Machine guns** are automatic rifles, using small-arms ammunition.

162. **Small arms** include rifles that are fired from the shoulder, and pistols that are fired from the hand.

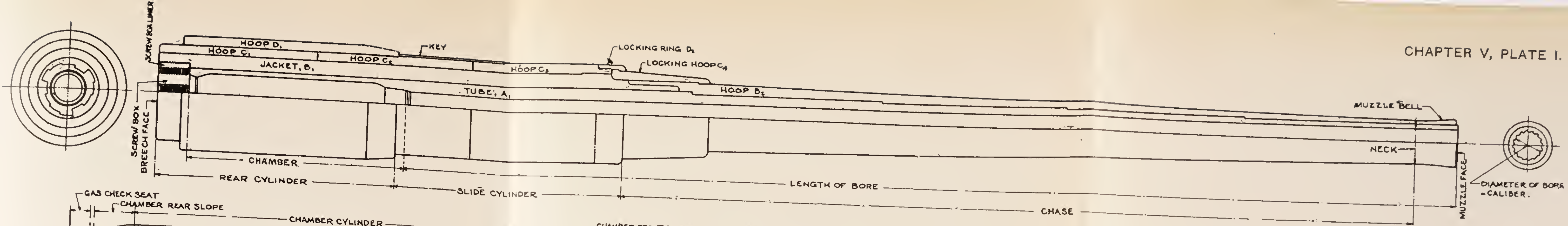
163. **Sub-caliber guns.**—A gun is called a *sub-caliber gun* when it is used mounted inside or outside a larger gun, for short-range gunnery practice. One-pounders and small-arms rifles are used for this purpose.

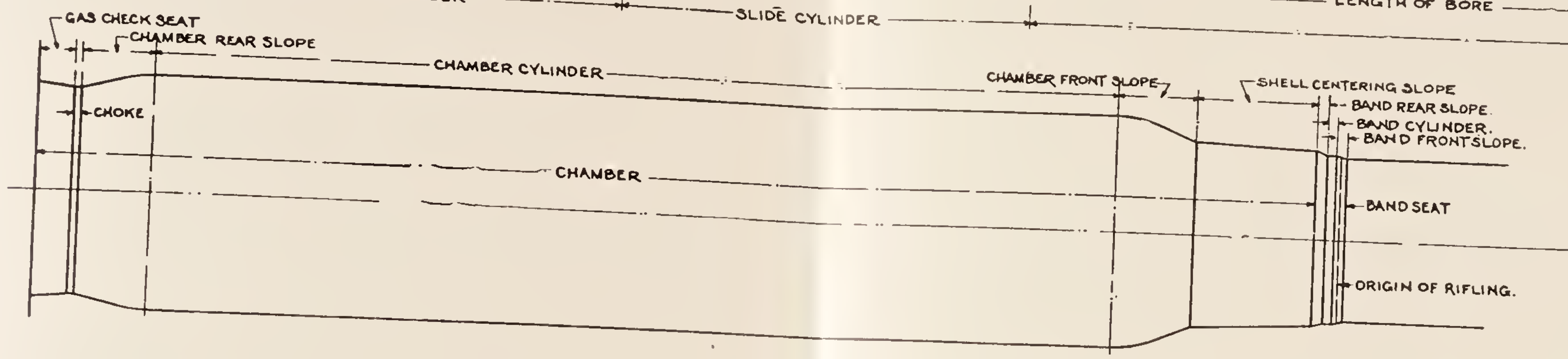
164. **Designation of guns.**—Guns are usually named or designated either by (1) caliber in inches, followed by the length of bore in calibers and the mark of the gun; or by (2) weight of projectile expressed in pounds for small-caliber guns (1-pounders to 6-pounders), followed by the mark of the guns. Thus: 14-inch, 45-caliber, Mark I, Mod. I.

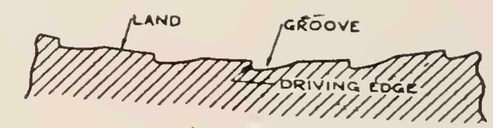
All guns of the same caliber, but of a different design, are distinguished from one another by being given different marks. The first design built of a caliber is called Mark I. If a new design is built with either new exterior or new interior dimensions, giving different ballistics from the previous design, this design is given a new mark, as, for instance, Mark II. If, however, a finished gun is modified, it retains the same mark, followed by a modification number, as 12-inch, Mark VII, Mod. II (the second modification made on Mark VII, 12-inch gun). Thus the 14-inch, Mark I gun, on being relined, would be designated as 14-inch, Mark I, Mod. I gun.

The usual *service method* is to write the caliber and the mark only; thus: 8-inch, Mark V, Mod. I.

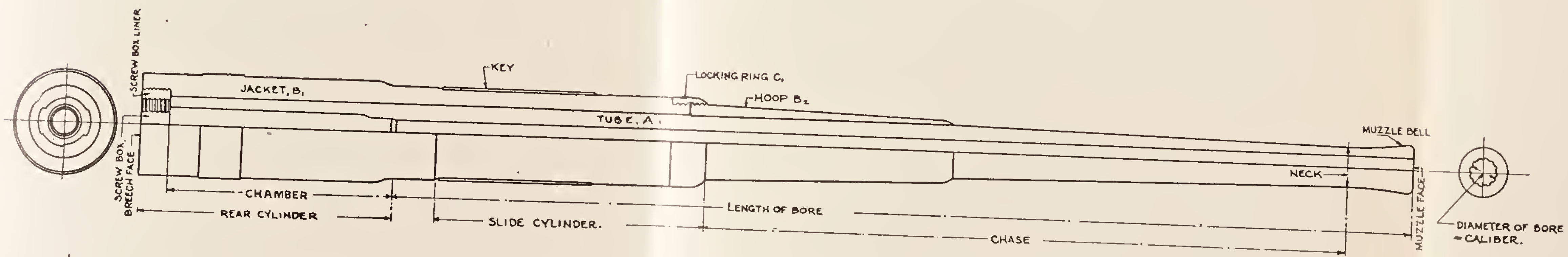
This system of marking is carried out throughout ordnance, not only for guns, but for gun mounts, breech mechanisms, sights, powder tanks, firing locks, and, in fact, most articles that are units in themselves.



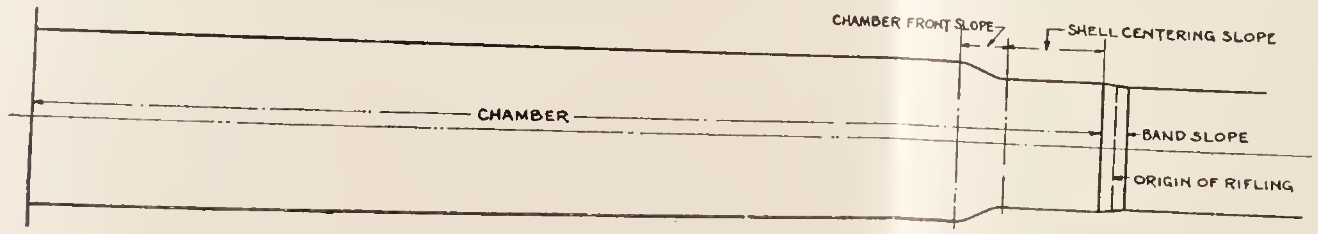




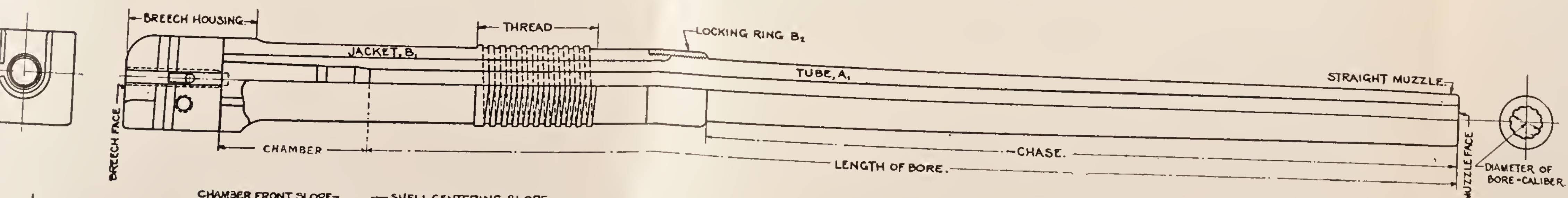
HOOK RIFLING.

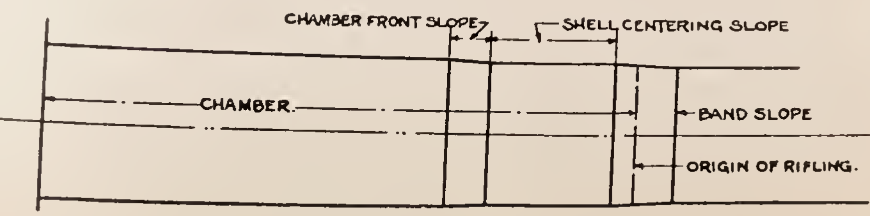


RIB RIFLING.



$$\text{LENGTH IN CALIBERS} = \frac{\text{LENGTH OF GUN IN INCHES}}{\text{DIAMETER OF BORE IN INCHES}}$$





GUNS MISCELLANEOUS.

GUN NOMENCLATURE.

165. Guns are classed on board ship (1) by calibers, and (2) by batteries.

(1) **Classed by calibers,** they are called "*major,*" "*intermediate*" and "*minor*" caliber guns.

Major caliber guns include all guns of 8-inch and above.

Intermediate caliber guns include all 4-inch, 5-inch, 6-inch and 7-inch guns.

Minor caliber guns include all calibers greater than "small arms" and less than 4-inch.

(2) **Classed by batteries,** the guns of a ship consist of "*main,*" "*secondary*" and "*anti-aircraft*" batteries.

The *main battery* in turret vessels includes all turret guns. In all other vessels it includes all guns except those specially designed for use against aircraft or for use in throwing depth charges.

The *secondary battery* in turret vessels includes all guns except turret guns, anti-aircraft guns, and depth charge projectors.

The *anti-aircraft battery* includes all guns carried for primary use against aircraft.

The term "*depth charge projector*" includes any apparatus for launching depth charges.

Rifling of Guns.

166. Advantages of rifling.—The penetration of oblong projectiles, other things being equal, is much greater than can be realized with spherical shot, while the bursting charge of oblong shells is as great as, or even greater than, that of spherical shells, on account of their greater length. These are very substantial advantages; but to secure them it is essential that the oblong projectile should keep point foremost in its flight; otherwise it would have neither range, accuracy nor penetration, but would waste its energy beating the air.

The only way to secure steadiness of flight to an oblong projectile is to keep its geometrical axis in the tangent to the trajectory it describes by giving it a high rotary velocity about its axis, thus imparting to it the properties of a gyroscope, whereby it resists angular motion. This is accomplished by *rifling,* as it is called; that is, by cutting spiral grooves in the surface of the bore into which a projecting copper band, securely encircling the projectile near its base, is forced as soon as the motion of translation

begins, thus giving to the projectile a rotary motion in addition to its translation as it moves down the bore. The rifling may be such that the grooves (or *rifles*) have a constant pitch—that is, make a constant angle with the axis of the bore—or this angle may increase gradually. In the first case the gun is said to be rifled with a *constant twist,* and in the second case with an *increasing twist.* In all cases the twist at any point of the bore is measured by the linear distance the projectile would advance while making one revolution, supposing the twist at that point to remain constant. This linear distance is always expressed in calibers, and is therefore independent of the unit of length employed. (See Art. 628.)

Gun Construction.

167. Present requirements for guns demand muzzle velocities of from 2500 to 3150 feet per second. Lower velocities give less striking force, and, more important still, a projectile fired at low velocity would describe a curve so high in the air, for long ranges, that hits could not be made unless the range were known with great accuracy. Since the accurate determination of range is the most difficult problem in naval gunnery, the high-power gun is a necessity. High velocity of projectile is produced, of course, by high pressure upon it while traveling through the bore. No heavy gun of a single piece of metal, whether cast or forged, could withstand the high pressures generated within the gun, and therefore the peculiar methods of modern gun construction are employed.

A gun may be considered as a tube designed to withstand a given pressure from within, throwing a projectile which shall produce certain effects at given distances. In constructing such a tube, we must first consider what pressures it will have to withstand at the various points of its length, and then make it strong enough to insure perfect safety. The bore should also be of such material as to stand the wear and tear of firing a large number of rounds without being so damaged by expansion or abrasion as to interfere with the shooting.

Not only must be gun be sufficiently strong, but it must not be too heavy ; so it is important that the material shall be arranged in such a manner that there may be no waste of its strength—in fact, so arranged that every part shall perform its own share in withstanding the pressure from within. Shortly after the shot

begins to move, the pressure inside the gun decreases, and continues to decrease as the projectile approaches the muzzle; for this reason the gun is made stronger at the powder chamber than toward the muzzle end.

The designing of guns, like the manufacture of other ordnance material, is the gradual development and improvement of a type, as the result of years of practical experience in perfecting models as needed to meet the increasing ballistic demands.

168. The three general subdivisions of the preliminary gun design are: (1) The *mechanical,* (2) the *ballistic,* and (3) the *service conditions.*

(1) **The mechanical conditions.**—It is necessary that the gun should be able to resist the pressures developed in the bore when fired. This is accomplished by the choice of a suitable material, and by a careful determination of the method of assembling the various constituent parts of the gun.

(2) **The ballistic conditions.**—The gun is designed to produce a certain ballistic result under the best possible conditions. The formulas of interior ballistics enable one to determine the weight of charge, the density of loading, and the quickness of the powder to be used. From these are deduced the dimensions of the powder chamber.

(3) **The service conditions.**—The gun should meet the requirements of service afloat in regard to loading, elevating, the operation of the breech mechanism, relining of gun, etc. These requirements affect the forcing cone, the outline of the powder chamber, the type of breech mechanism, the center of gravity, and the weight.

169. Stresses.—Looking simply to the construction of a gun cylinder, we find that the two principal stresses to which such a cylinder is subjected upon the explosion of a charge are, first, a circumferential or *tangential stress* or tension, coupled with a *radial stress,* tending to split the gun open longitudinally; second, a *longitudinal stress* tending to pull the gun apart in the direction of its length.

It has been ascertained as the result of experiment that the greatest stress experienced by the metal of the gun is the tensile stress set up in the direction of its circumference by the pressure of the powder gases; in addition, it also experiences a longitudinal stress.

The least complicated method of making a gun would seem to be that of casting it as a homogeneous hollow cylinder; but if we take such a tube, made of one material throughout, we find that its tangential strength to resist a pressure from within does not increase uniformly with its thickness.

If now we exert pressure upon the tube from without, the initial pressure exerted by the powder gases must first neutralize this outside pressure before it can subject the tube to any additional tensile stress. The amount of the external pressure must not, however, exceed the elastic limit of the metal, as otherwise permanent deformations would be produced in the inside layers of the gun. The amount of the external pressure must be so computed that the tensile strength of the metal of the bore of the tube will be fully utilized in firing, and it must therefore merely equal the difference between the gas pressure and the limit of resistance to tensile strain of the metal.

We find, practically, that with a given material we soon reach a limit beyond which *any additional thickness of wall aids but little* in enabling the cylinder to withstand pressure. Supposing the metal to be incompressible, this limit is taken at about half a caliber, so that—for example in the cylinder of an hydraulic press —if the thickness of the walls be equal to one-half the diameter of the piston which works inside, then the cylinder will be nearly as strong as if it were ten times as thick.

It is generally conceded that no possible thickness can enable a simple cylinder to bear a continued pressure per square inch from within *as great* as the tenacity of a square-inch bar of the same material; that is to say, if the tensile strength of cast iron be 12 tons per square inch, no cast-iron gun, however thick, could bear a charge which would exert that pressure on each square inch, for, on the first round the interior layer would be ruptured before the outer portion could come into play, and every succeeding round would tend to make matters worse.

From the above it is clear that guns made by simply casting or forging iron, bronze, or steel into homogeneous cylinders cannot be made strong enough. The working pressure which we require a high-power gun to withstand is not less than 18 tons per square inch, and we require, further, that this pressure shall not strain the gun beyond the elastic limit of the metal, in order that the bore

of the gun shall not be permanently enlarged. The elastic limit of cast steel is from 15 to 20 tons per square inch, and since steel has a higher elastic limit than either iron or bronze, allowing a margin of safety, it will not do to make a high-power gun of cast homogeneous metal even when we use steel. We must resort, then, to what is termed the *built-up system*, and it can be shown mathematically that a built-up gun, properly constructed, of the same dimensions and material as a homogeneous gun, is much stronger than the latter.

170. Having decided upon the built-up gun, we accept as axiomatic and fundamental the following:

Basic law of gun construction.—*No fiber of any cylinder in the gun must be strained beyond the elastic limit of the metal of that cylinder.*

Attention is called to the word "strained" in this law. This law is stated again in paragraph 188 in a much fuller form, and we see that it is not the forces or "stresses" acting (for one may balance another), but the "strain" or deformation resulting from their joint action that limits us.

171. To satisfy this law there are two "principles" of construction: (1) "varying elasticities" and (2) "initial tensions."

(1) **The principle of varying elasticities.**—This consists of placing that metal which stretches most *within its elastic limit* around the surface of the bore, so that by its enlargement the explosive stress is transmitted to the other parts exterior to it. This method is exemplified in guns which have a steel tube surrounded by wrought-iron coils, and in the Palliser system, in which a wrought-iron or steel tube is surrounded by cast iron. With different grades of steel—high and low steel, for example—the steel which shows the greater elongation within the elastic limit is the more suitable to be placed next to the bore. Carrying out this theory in practice is another matter, because in the case of very long tubes there is more difficulty and uncertainty of manufacture with the higher grades of steel than with the lower, and the difficulty increases with the size. *For this reason the principle of varying elasticities is only applicable where the different parts of a gun are made of different metals.*

(2) **The principle of initial tensions.**—This consists in giving to the exterior portions of the gun a certain initial tension, gradu-

ally decreasing toward the interior, and giving to the interior parts a certain normal state of compression by the grip of the outer cylinders and coils.

If by the system of initial tensions the interior can be put in a state of compression, within the elastic limit of the metal, the amount of that compression is so much additional strength, since it must first be overcome before the powder gases can exert a tension on the fibers of the interior tube. In order to exert compression, then, the outer coils or hoops must be in a state of normal tension, and in addition to that they must have a margin of strength within their elastic limits to withstand the additional tension transmitted by the explosion of the charge, this additional tension being, of course, much less than would be put upon *free metal* next the bore.

The exact amount of tension and compression for all parts of the gun when at rest, or when resisting the explosion of the charge, so that all parts shall be strained to a point not exceeding their elastic limit, is a matter for mathematical calculation, and is treated at length in works on the theory of gun construction.

Owing to the difficulty of obtaining the proper graduations of elasticity from cylinder to cylinder, as is necessary under the "principle of varying elasticities," we have adopted the "principle of initial tensions" for the construction of the guns for our service.

Having adopted "initial tensions" as the principle of construction to follow for our guns, it remains to describe, in general terms, how the thickness of the walls and the "shrinkages" are determined.

172. Thickness of walls.—By the principles and formulas of Interior Ballistics, Chapter III, we can find the pressure of the powder gases at any point of travel of the projectile through the bore. By solving for a number of points and plotting them on the axis of the gun, with the pressures as ordinates and the travel of the projectile as abscissæ a curve of pressures can be constructed for a given powder that will approximate to the truth for practical purposes; a good margin of safety is always allowed, and the various thicknesses of metal to withstand the pressures at different points of the length of the bore follow at once, the caliber and length of the gun having previously been fixed by the amount of work the gun is expected to perform.

173. After the preliminary drawing of the gun has been completed, the elastic strength to resist powder pressure is computed at all points, together with the shrinkages. The strength curve is then compared with the pressure curve, and if there is not a sufficient margin of safety, a readjustment of the dimensions of the parts of the gun is made, and the elastic strength is recomputed. It is also necessary to compute the stresses which the parts undergo in the *state of rest* to determine that the tube will not be crushed by the shrinkage.

An example of a pressure curve plotted with a strength of gun curve is shown in Chapter III, Plates II and III.

174. Shrinkage.—Practically, the compression of the interior and tension of the exterior are effected in manufacture, after the amounts for each have been calculated, (1) by *shrinkage,* (2) by forcing upon one another by hydraulic pressure two cylinders having slightly coned surfaces, or (3) by winding steel wire, or riband, over a steel tube.

If the method of shrinkage be employed, the hoops or tubes to be shrunk on must be accurately bored, and the outer cylinder must be expanded by heat until it is sufficiently large to slip over the inner. The inner diameter of the outside cylinder when cold must be a little smaller than the outside diameter of the inner tube, and this difference of diameters is called the *shrinkage.* While the outer cylinder is cooling and contracting it compresses the inner one, making the diameter of the latter a little smaller than before. The amount by which the exterior diameter is decreased is called the *compression.*

Again, the outer cylinder itself is stretched on account of the resistance of the inner one, and its interior diameter is slightly increased. This increase is called the *extension.*

The *shrinkage* is always equal to the *compression* plus the *extension,* and the exact amount must be previously calculated by the known extension and compression of various metals under certain stresses and given circumstances.

The principle of initial tensions, carried to an extreme limit, would be exemplified in the case of a gun composed of an infinite number of infinitely thin hoops properly shrunk together. When so assembled, the tension in a gun, when the powder pressure acts, would be uniform throughout the thickness. The greater the

number of hoops the nearer this theory is approached in practice, but there are practical difficulties in manufacturing, such as the accurate machine work necessary and the greatly increased cost; for this reason it is not considered practicable to use more than four layers in the case of guns now designed. In the case of wire guns, or ribbon-wound guns, this theory is better exemplified, and when successful manufacture is possible in these cases, stronger guns of the same weight must be the result.

175. **The wire-wound gun.**—As stated above, this is an example of the initial-tension system. The wire is wound in layers around an inner tube of steel. Each layer is wound with a different tension of the wire, and each exerts a compression on the layers which are inside of it. The result is that, when completed, the outer layers are in extension, gradually diminishing to the inner layers, which are in compression—all within the elastic limit. As wire can be made of enormous strength (as much as 200,000 pounds per square inch tensile strength), this type of gun is the strongest for the same weight of any yet developed.

CHAPTER VI.

ELASTIC STRENGTH OF GUNS.

Section I.—Preface.

176. This chapter was first published as a small book, prepared primarily for use by the midshipmen at the U. S. Naval Academy, by Professor Philip R. Alger.

It is here included in this general treatise on Ordnance almost verbatim, there being no changes introduced, but some of the deductions and derivations have been expanded to show more clearly how certain results are obtained.

The chapter essays to present the subject of the elastic strength of guns as concisely as is consistent with clearness, and to that end treats only of steel guns of modern construction.

The hypothesis that permanent set will not occur unless the resultant *strain* in some direction exceeds the limit of elastic strain, regardless of what the stresses may be, is adopted. This hypothesis appears to the writer to be the only reasonable one, but it is to be regretted that its truth has never been demonstrated experimentally.

The longitudinal stress is taken to be zero, an assumption made by Claverino in his first treatise on the "Resistance of Hollow Cylinders," published in the "Giornale d'Artiglieria" in 1876, and adopted by Birnie in his exhaustive studies of the resistance and shrinkages of built-up cannon.

Wire-wound guns, though built on the principle of initial tension, are not treated here. The theory and formulas on this subject can be found in the original text on elastic strength by Professor Alger.

A number of illustrative examples are solved in the text, and others, with their answers, follow each section.

INTRODUCTORY.

177. **Stress and strain.**—We give the name *stress* to a mutual action between the parts of a body, or between one body and another, causing or tending to cause them to move relative to one

another; it is any pair of equal and opposite actions each of which is what is called a force.

Thus, if a rope be stretched vertically downwards from A to B, we speak of the tension T of the rope as the force T acting downward on A, or as the force T acting upward on B, according as we are considering A or B; but we speak of the action in the rope, which tends to break it, as the stress in the rope.

178. We call the change of volume or figure of any solid or liquid under the action of force a *strain*.

Thus, if a bar is lengthened or shortened, it is strained; a compressed liquid is strained; a stone, a piece of metal, or other part of any structure, is said to experience a strain if it be bent, or twisted, or compressed, or dilated, or in any manner distorted. Furthermore, any change in the configuration of a group of bodies whose relative positions are subject to fixed conditions is called a strain. Thus, any structure is said to strain when its different parts experience relative motion, as, for example, a ship "strains" in a seaway.

179. If we imagine any plane area within a strained body as forming a division between the parts of the body on either side of it, then the force which each of the two parts exerts upon the other is one of the pair of forces which constitute the stress on the area. In other words, the stress on any sectional area is the pair of equal and opposite actions which hold the area in its state of strain.

180. *The intensity of stress* is the number of units of force per unit of area. We shall always express it in tons weight, or pounds weight, per square inch; and, for brevity, we shall use the word stress as meaning "intensity of stress," always applying the term "total stress" to the whole force acting on any area. If the intensity of the stress (p) is the same at all points of a given area (A), the stress on the area is said to be uniformly distributed, and P being the total stress on the area, we have $p = \frac{P}{A}$. If the stress is not uniformly distributed, its intensity at any point is given by $p = \frac{dP}{dA}$, where dP is the total stress on the elementary area dA.

181. Hook's law.—Every stress is accompanied by a strain, and experiments show that in all solid bodies the strain is propor-

tional to the stress which causes it, provided the stress does not exceed certain limits which vary with the material. This is what is known as *Hook's law*—" *ut tensio sic vis*" (*as the extension so the force*).

182. The simplest form of stress is that which exists in a bar of uniform section to which equal and opposite forces are applied axially, tending to lengthen or shorten it. If the forces act to lengthen the bar, the stress is called tension, and if they act to shorten it, the stress is called compression; but mathematically considered compression is merely negative tension.

The strains accompanying tension are an elongation in the direction of the pull and a contraction in all directions perpendicular to it; while the strains accompanying compression are the reverse, *i. e.*, a shortening in the direction of the push and an expansion in all directions perpendicular to it. These strains are elastic, that is, they disappear with the removal of the forces which caused them, so long as the tension—or the compression, as the case may be—does not exceed a value which is called the *elastic limit* of the material. Within that limit the strains follow Hook's law.

183. If P be the total pull (or push) on the bar, and A be the area of its right section, the total stress on any such section is P, and, since it is uniformly distributed, its intensity is $p = \frac{P}{A}$. The *elastic limit* * is the value of p beyond which the strain ceases to be wholly elastic; if this value is exceeded, the bar takes a permanent set, *i. e.*, when released it will be found to be longer (or shorter) than it was originally. With some materials, notably cast iron, the elastic limit under compression considerably exceeds that under tension, but in the case of steel the difference, if it exists, is not important. The elastic limit of the steel forgings used in modern gun construction is from 35,000 to 75,000 pounds per square inch.

184. The modulus of elasticity.—Within the elastic limit the ratio of stress to strain is, by Hook's law, a constant, and the value of this constant for the case of simple tension or compression is

* Some writers use the term elastic limit to denote the greatest elastic *strain* under simple tension or compression, instead of the greatest *stress* causing only elastic strains. We shall use the term *elastic limit of strain* to distinguish the former concept, and shall use *elastic limit* to denote the *elastic limit of stress*.

called the *modulus of elasticity* and is denoted by E. That is to say, if e is the change of length per unit length under the stress $p=\frac{P}{A}$, then $E=\frac{p}{e}$.

Since e is the relative, not the total, strain, it is an abstract number, being, in the case considered, the total change of length of the bar (due to its tension or compression) divided by its length when free. Consequently E is a quantity of the same kind as p and its value depends upon the units in which p is expressed.

When p is given in pounds per square inch, E has the value 29,000,000 for steel; when p is expressed in tons per square inch, E has the value 13,000.

Evidently E is the stress which would double the length of a bar under tension (if it continued to obey Hook's law to that point), since when $e=1$, $p=E$.

It must be understood that E is the value of the stress on a right section of the bar divided by the strain perpendicular to that section, or in the direction of the external forces causing the strain; the strains at right angles to the axis of the bar, though proportional to the principal strain, are less in value, their ratio to it, determined by experiment, being, in this work, taken to have the value $\frac{1}{3}$.*

185. Example.—As an example, suppose a round steel bar, 2 inches in diameter and 20 inches long, to be under a tension of 60 tons; then the stress on a right section of the bar is $p=\frac{P}{A}$ where $A=\pi r^2$. But $d=2'' \therefore r=1''$, hence $A=\pi$ from which $p=\frac{P}{\pi}=\frac{60}{\pi}=19.1$ per square inch; the strain in the direction of the axis of the bar is $e=\frac{p}{E}=\frac{19.1}{13000}=.00147''$; and the strain at right angles to the axis is $\frac{.00147}{3}=.00049''$. The length of the bar is increased by the tension $20\times.00147=.0294$ inches, making its

* This quantity is known as "Poisson's ratio" from the great French mathematician. Its value varies for different materials, and for steel has been taken by different authorities as ½, ⅓ and ¼. The best modern experiments assign to it a value in the neighborhood of ⅓.

strained length 20.0294 inches; and its diameter is diminished $2 \times .00049 = .00098$, making its strained diameter 1.99902 inches.

If the force of 60 tons were applied to compress the same bar, it would be shortened .0294 inches and its diameter would be increased .00098 inches.

Under tension the volume of the bar is increased in the ratio 1 to 1.000488; while under compression its volume is diminished in the same ratio.

186. If more than one pair of equal and opposite forces act upon a body, the stress upon any sectional area of the body is the resultant of the stresses which would be caused by the pairs of forces acting separately; and the strain at any point due to the

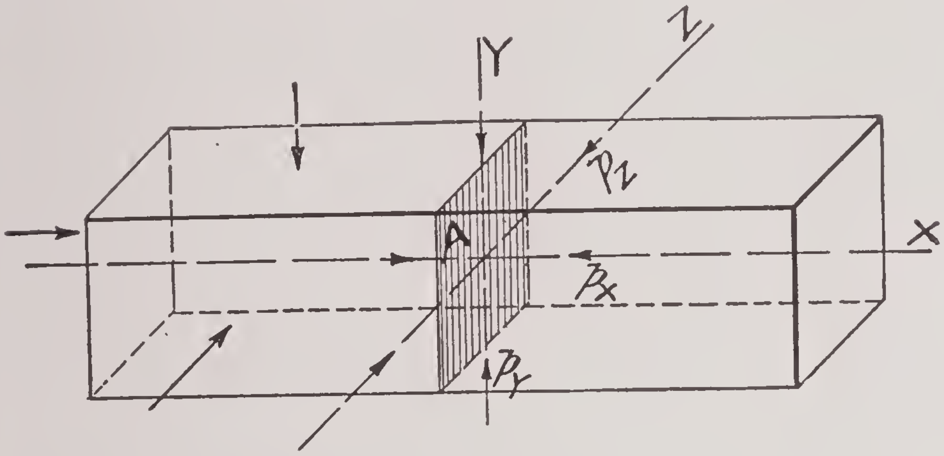


FIG. 27.

simultaneous action of all the stresses is obtained by simply superposing the strains due to the different stresses taken separately.

Thus, taking a rectangular right prism with equal and opposite forces acting normally upon each pair of its opposite faces, let X, Y and Z be the forces acting *per unit area* of the respective faces: then the stress on each right section perpendicular to the X axis will be X, the stress on each right section perpendicular to the Y axis will be Y, and the stress on each right section perpendicular to the Z axis will be Z. Also, at each point in the prism, the resulting strains in the directions of the axes will be:

$$\left.\begin{aligned}
&(a) \quad e_x = \frac{1}{E}\left(X - \frac{Y}{3} - \frac{Z}{3}\right),\\
&(b) \quad e \;\,= \frac{1}{E}\left(Y - \frac{Z}{3} - \frac{X}{3}\right),\\
&(c) \quad e_z = \frac{1}{E}\left(Z - \frac{X}{3} - \frac{Y}{3}\right)
\end{aligned}\right\} (1)$$

In these expressions e_x, e_y and e_z are the changes of length per unit length in the directions of the X, Y and Z axes, respectively, and are plus when they are lengthenings and minus when they are shortenings, provided the stresses X, Y and Z are given plus signs when they are tensions and minus signs when they are compressions.

187. Evidently if either Y or Z be of opposite sign to X, the strain in the X direction may be greater than $\frac{X}{E}$, and similarly the strains in the Y or Z directions may be either greater or less than $\frac{Y}{E}$ and $\frac{Z}{E}$ respectively, according as X, Y and Z are unlike or like forces. If, for example, $X=15$ tons per square inch tension, and Y and Z are each 15 tons per square inch compression, we have $e_x=\frac{1}{E}\left(15+\frac{15}{3}+\frac{15}{3}\right)=\frac{25}{13000}=.001923$, and the prism would lengthen .001923 inches per inch of its free length instead of only $\frac{15}{E}=.001154$ inches per inch, as would be the case if the stress X alone acted.

188. In our investigations of the strength of guns we accept the following principle:

The total strain in any direction due to all the stresses is the measure of the tendency to yield in that direction, so that the limit of elastic strength is reached, not when the stress in any direction equals the elastic limit of the material, but when the strain in any direction equals the strain which would be caused by the direct action of a single stress equal to that elastic limit.

If, for example, a steel forging has an elastic limit of 58,000 pounds per square inch, *i. e.*, if 58,000 pounds per square inch is the greatest simple tensile stress which the steel will withstand without permanent lengthening, then for the safe use of such a forging it is necessary, and sufficient, that at no point within it shall the strain at any time exceed $\frac{58000}{E}=\frac{58000}{29000000}=.002$ inches per inch in any direction.

189. At any point in a strained solid there are always three planes, at right angles to one another, upon each of which the stress is wholly normal. These three simple stresses (tensions or

compressions) are called the *principal stresses* at the point, and their directions are called the *principal axes of stress.*

In the case we are about to investigate—a hollow cylinder under internal and external fluid pressure—the principal axes of stress are evidently radial, circumferential, and longitudinal (parallel to the cylinder's axis), and the principal stresses, which we denote by p, t and q, are illustrated in Fig. 28, where one of the elementary

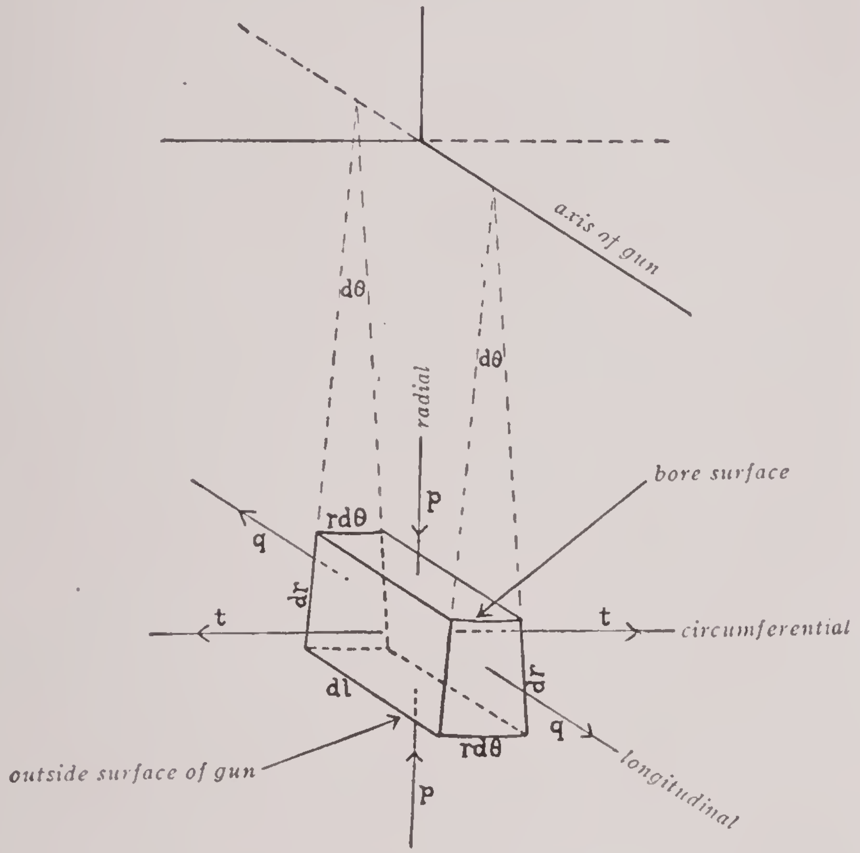


Fig. 28.

prisms of which we imagine the cylinder to be composed is shown in equilibrium under their joint action.

The strains in the directions of the principal axes of stress are called the *principal strains;* they are simple longitudinal strains (lengthenings or shortenings), and their relations to the principal stresses are those given by equations (1).

190. Since the external pressures with which we are to deal are compressive forces, it will be convenient to call the radial stress (p) plus when it acts to compress the material of the cylinder,

though continuing to call the circumferential stress (t) and the longitudinal stress (q) plus when they produce tension.* With this convention, equations (1) become:

$$\left.\begin{aligned}
&(a)\quad e_t = \frac{1}{E}\left[t + \frac{p}{3} - \frac{q}{3}\right]\\
&(b)\quad e_p = -\frac{1}{E}\left[p + \frac{q}{3} + \frac{t}{3}\right]\\
&(c)\quad e_q = \frac{1}{E}\left[q - \frac{t}{3} + \frac{p}{3}\right]
\end{aligned}\right\}(2)$$

in which e_t is the strain in the direction of the circumference, e_p the strain in the direction of the radius, and e_q the strain in the direction of the axis of the cylinder, in each case a plus value indicating extension and a minus value compression.

In the theory of elasticity it is shown that if an ellipsoid be constructed with semi-axes representing the principal stresses at a point, the stress upon any plane at the point is represented in magnitude and direction by a radius vector of the ellipsoid, which is called the ellipsoid of stress. Evidently, then, one of the three principal stresses acting at each point in a strained solid is the greatest stress at the point. In a similar way it is shown that one of the three principal strains at a point is the greatest strain at the point.

EXAMPLES.

(1) A round steel rod 1 inch in diameter and 6 feet long is found to stretch .07 inches under a load of 10 tons. What is the intensity of the stress on its transverse section, and what is the value of the modulus of elasticity?

12.73 tons per sq. in.; 13,096 tons.

(2) What length of uniform steel rod, hanging vertically, will just carry its own length, if the maximum allowable stress is 8 tons per square inch (steel weighs .283 lb. per cu. in.)?

5277 ft.

(3) The ends of a steel I-beam whose flanges are 8 inches wide rest on stone supports. If each support takes half the total load of 20 tons, what should the length of bearing surface be, the safe compression stress for stone being 300 lbs. per square in?

9.3 in.

* See footnote under Art. 219.

(4) A bar of steel 2 inches in diameter is bent so that its axis forms the arc of a circle of 372 ft. diameter. What is the greatest strain at any point of the transverse section, and what is the greatest stress? (*E* for steel is 29,000,000 lbs. in.)

.000448; 12,992 lbs. per sq. in.

(5) A steel bar, 10 inches long and of square section, 1 inch on the side when free, is under 40,000 pounds tension. What are its dimensions under this stress, which is within the elastic limit?

$10.0138 \times \overline{.99954}^2$.

(6) A copper rod of square cross-section, 2 inches on the side, and 5 feet long, stretches .0375 inches under a load of 40,000 pounds. What is the modulus of elasticity, and what is the cross-section while the bar is under this stress?

16,000,000 lbs. in.; 3.9983.

(7) A one-inch square steel bar of 32,000 lbs. elastic limit is under a tension of 24,000 lbs.; what pressure per square inch on all of its sides will cause it to lengthen permanently? 12,000 lbs.

(8) If a cube be subjected to equal tensions, or compressions, in each of the three directions normal to its opposite pairs of faces, what relation must exist between the stress of tension, or compression, and the elastic limit of the material in order that the cube may be permanently strained? $p = 3\theta$.

(9) The modulus of elasticity of copper being 16,000,000 (lbs. in.), how much will the length and diameter of a round copper rod, 20 inches long and 3 inches in diameter when free, change under a tensile stress of 9000 lbs. per sq. in.?

.01125 in.; .00056 in.

(10) In order to bring to the vertical opposite walls which have fallen away from each other, round steel rods of 1 in. diameter are stretched from wall to wall and after being heated to 400° C. are set up taut. What pull will each rod exert when its temperature has fallen to 200° C., supposing the walls not to have yielded at all? The coefficient of expansion of steel is .000011 for 1° C.

50,100 lbs.

(11) How much would the steel rod of example (2), which is 5277 ft. long when free, be increased in length by the stress due to its own weight? 19.56 in.

Section II.—Stress and Strain in Simple Hollow Cylinders.

191. Consider a horizontal hollow cylinder, open at the ends, which are faced off in planes normal to the axis; and let this cylinder be filled with a fluid which is forced inward by two expanding plungers, the result being a uniform normal pressure upon the entire internal surface of the cylinder. Also let the entire outer cylinder surface be subjected to a fluid pressure. Then, the ends of the cylinder being free, and there being no longitudinal stress upon its walls, it is clear that the cylinder will remain a cylinder under the action of the pressures, and that each transverse section normal to the axis will remain a plane normal to the axis. Whatever shortening or lengthening of the cylinder may result from applying internal and external fluid pressure to it must be

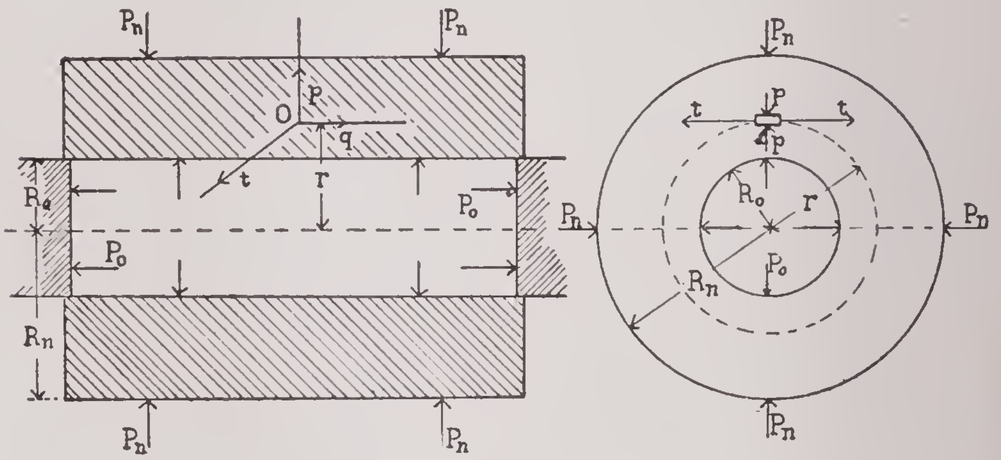


FIG. 29.

uniform over its whole cross-section; *i. e.*, the longitudinal strain must, under the stated conditions, be constant throughout the cylindrical walls.

192. Let O be any point (of radius r) within the walls of a cylinder (Fig. 29) whose inner and outer radii are R_0 and R_n, and which is subjected to internal and external pressures P_0 and P_n respectively. Also let t, p and q be the circumferential, radial and longitudinal stresses, and e_t, e_p and e_q the circumferential, radial and longitudinal strains, at the point O, E being the modulus of elasticity of the material. And let T_0 and T_n be the circumferential tensions at the inner and outer surfaces, or the values of t when $r = R_0$ and when $r = R_n$.

In the strained cylinder, the principal stresses at the point O are evidently the radial pressure p, which varies in value from P_0 at

the inner to P_n at the outer surface; the circumferential tension t, which varies from T_0 at the inner to T_n at the outer surface; and the longitudinal stress q, which is zero in the particular case considered but which might be either tension or compression and either constant or variable. From equations (2), therefore, we obtain as the values of the principal strains,

$$\left.\begin{aligned} &\text{(a)}\quad e_t = \frac{1}{E}\left(t+\frac{p}{3}\right), \\ &\text{(b)}\quad e_p = -\frac{1}{E}\left(p+\frac{t}{3}\right), \\ &\text{(c)}\quad e_q = -\frac{1}{E}\left(\frac{t}{3}-\frac{p}{3}\right). \end{aligned}\right\} \quad (3)$$

and since, under the stated conditions, e_q is constant, we obtain from (c) above

$$* \; t-p = \text{constant} = k. \qquad (4)$$

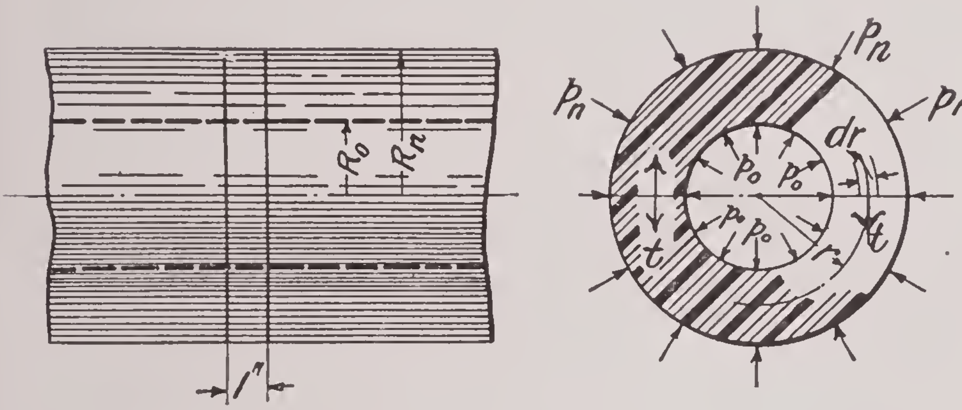


FIG. 30.

193. Considering any section of the cylinder (see Fig. 30) of unit length, if the cylinder is cut longitudinally by a diametral plane, the whole pressure acting outward upon the section is $2P_0R_0$, and the whole pressure acting inward upon the section is $2P_nR_n$, so that the total force tending to burst the cylinder is $2P_0R_0 - 2P_nR_n$. This force must be balanced by the total stress developed in the two sections of the cylinder walls, each of which is $\int_{R_0}^{R_n} tdr$, which total stress is $2\int_{R_0}^{R_n} tdr$.†

* It should be noted that this same result, $t - p =$ constant, follows when q is constant as well as when q is zero.

† We here assume the cylinder to be of unit length.

194. Since we have equilibrium the disruptive forces and the resistance are equal, and we have

$$\int_{R_0}^{R_n} t\,dr = P_0R_0 - P_nR_n. \tag{5}$$

Since this is true the general equation expressing the same thing must be true, or $\int t\,dr = -pr$. But the differential of

$$-pr \text{ is } -p\,dr - r\,dp, \therefore t\,dr = -p\,dr - r\,dp,$$

from which we obtain

$$t = -p - r\frac{dp}{dr}. \tag{6}$$

From (4) we have $t = p + k$, and equating the two values of t we have $p + k = -p - r\dfrac{dp}{dr}$, or

$$2p + k = -r\frac{dp}{dr}. \tag{7}$$

From (7) we obtain the expression $\dfrac{dp}{2p+k} = -\dfrac{dr}{r}$.

Integrating,

$$\int\frac{dp}{2p+k} = -\int\frac{dr}{r}, \therefore \tfrac{1}{2}\log(2p+k) = \log 1/r + \log k_1$$

(k_1 being a constant of integration).

$$\sqrt{2p+k} = \frac{k_1}{r},$$

and the integration gives

$$2p + k = \frac{k_1^2}{r^2}. \tag{8}$$

Substituting in (8) the value of k given in (4), we have

$$2p + t - p = \frac{k_1^2}{r^2},$$

or

$$t + p = \frac{k_1^2}{r^2}. \tag{9}$$

195. Equations (4) and (9) express what are known as *Lamé's Laws:* *

* As explained, these laws are only strictly true when the longitudinal stress is constant, or zero.

1. At any point whatever in a cylinder under fluid pressure the sum of the circumferential tension and the radial pressure varies inversely as the square of the radius.

2. The difference of the circumferential tension and the radial pressure is the same at all points.

196. These, then, are the equations which express the relation between the circumferential tension and the radial pressure at all points within the cylinder walls:

$$\left.\begin{array}{ll}\text{(a)} & t-p=k=T_0-P_0=T_n-P_n,\\ \text{(b)} & (t+p)r^2=k_1{}^2=(T_0+P_0)R_0{}^2=(T_n+P_n)R_n{}^2.\end{array}\right\} \qquad (10)$$

From the last part of equation (10a) we obtain

$$T_n=T_0-P_0+P_n,$$

and from (10b) we obtain

$$T_n=\frac{(T_0+P_0)R_0{}^2}{R_n{}^2}-P_n.$$

Equating these values of T_n, and clearing the equation, we obtain

$$T_0=P_0\frac{R_n{}^2+R_0{}^2}{R_n{}^2-R_0{}^2}-P_n\,\frac{2R_n{}^2}{R_n{}^2-R_0{}^2}.$$

197. From the first parts of equations (10), we have

$$t-p=T_0-P_0,$$

$$t+p=\frac{(T_0+P_0)R_0{}^2}{r^2}.$$

By adding these two equations, we obtain

$$2t=(T_0-P_0)+\frac{(T_0+P_0)R_0{}^2}{r^2},$$

and by subtraction we obtain

$$2p=-(T_0-P_0)+\frac{(T_0+P_0)R_0{}^2}{r^2}.$$

These expressions for t and p are in terms of T_0 and P_0 only. To make them general we substitute in them the value of T_0 found above, and reducing we have

$$t=\frac{P_0R_0{}^2-P_nR_n{}^2}{R_n{}^2-R_0{}^2}+\frac{R_0{}^2R_n{}^2(P_0-P_n)}{R_n{}^2-R_0{}^2}\,\frac{1}{r^2}, \qquad (11)$$

$$p=-\frac{P_0R_0{}^2-P_nR_n{}^2}{R_n{}^2-R_0{}^2}+\frac{R_0{}^2R_n{}^2(P_0-P_n)}{R_n{}^2-R_0{}^2}\,\frac{1}{r^2}, \qquad (12)$$

and these equations enable us to determine the values of t and of p at any point.

198. Equations (3) give us general expressions for the strains in a cylinder in terms of t and p. But in this form the expressions are not available for use, for we desire them in terms of P_0, P_n, R_0 and R_n.

To obtain the equations in this form we substitute for t and p in the equations (3) the values of these principal stresses as found in (11) and (12), which then reduce to the equations

$$e_t = \frac{1}{E}\left[\frac{2}{3}\,\frac{P_0R_0^2 - P_nR_n^2}{R_n^2 - R_0^2} + \frac{4}{3}\,\frac{R_0^2R_n^2(P_0 - P_n)}{R_n^2 - R_0^2}\,\frac{1}{r^2}\right], \quad (13)$$

$$e_p = \frac{1}{E}\left[\frac{2}{3}\,\frac{P_0R_0^2 - P_nR_n^2}{R_n^2 - R_0^2} - \frac{4}{3}\,\frac{R_0^2R_n^2(P_0 - P_n)}{R_n^2 - R_0^2}\,\frac{1}{r^2}\right], \quad (14)$$

$$e_q = -\frac{1}{E}\left[\frac{2}{3}\,\frac{P_0R_0^2 - P_nR_n^2}{R_n^2 - R_0^2}\right]. \quad (15)$$

These are *general equations* and apply to all cases.

The first two of these equations are the fundamental ones from which we shall deduce all the formulas used in our study of the elastic strength of guns.

The greatest of the three strains given by (13), (14) and (15) for any point in the cylinder walls must not at any time exceed the elastic limit of strain of the material of the cylinder. That is, calling θ the elastic limit of the material, as determined in a testing machine, the limiting value for each of the three strains e_t, e_p and e_q is $\frac{\theta}{E}$.

As e_t and e_p denote the general values of the circumferential and radial strains (at any radius r), we shall distinguish the values of the circumferential and radial strains at radius R_0 by $e_t(R_0)$ and $e_p(R_0)$, and those at radius R_n by $e_t(R_n)$ and $e_p(R_n)$.

199. The quantities Ee_t, Ee_p and Ee_q, respectively, equal in value the simple stresses which, acting alone, would cause the strains e_t, e_p and e_q, but these strains are actually caused by the concurrent action of the two stresses p and t. We shall hereafter designate Ee_t, Ee_p and Ee_q as the *true stresses*, circumferential, radial and longitudinal respectively.

A cylinder may be under stress in three ways, *i. e.*, (1) interior pressure only; (2) exterior pressure only; and (3) both interior and exterior pressures simultaneously.

The distribution of the true stresses throughout the walls of a simple cylinder under fluid pressure is best shown graphically, and we will therefore do this for the three cases; first, when the outer pressure (P_n) is zero; second, when the inner pressure (P_0) is zero; and third, when both pressures act and P_0 is greater than P_n. In each case we *assume* a cylinder whose outer is three times its inner radius ($R_n=3R_0$), so that its walls are a caliber thick.

The series of equations that follow from this assumption are *specific* and hold only for the stated conditions. For other conditions of radii ratios we must go to equations (13), (14) and (15), substitute the given conditions therein, and deduce new equations which will of course be similar in form to those following in (16), (17) and (18), but will have different arithmetical figures.

General equations covering the three specific conditions in Arts. 200, 201 and 202 are deduced in Arts. 207, 209 and 211.

200. Case I.—No exterior pressure.—Putting $P_n=0$ and $R_n=3R_0$ in (13), (14) and (15), we obtain as the values of the true stresses:

$$\left.\begin{aligned}
&\text{(a)}\quad Ee_t = \frac{P_0}{12}\left(1+\frac{18R_0^2}{r^2}\right),\\
&\text{(b)}\quad Ee_p = \frac{P_0}{12}\left(1-\frac{18R_0^2}{r^2}\right),\\
&\text{(c)}\quad Ee_q = -\frac{P_0}{12}.
\end{aligned}\right\}\quad(16)$$

From these it will be seen that as r increases from R_0 to R_n the circumferential true stress diminishes from $\frac{19}{12}P_0$ to $\frac{3}{12}P_0$, its value midway, where $r=2R_0$, being $\frac{11}{24}P_0$; the radial true stress diminishes (algebraically it increases) from $-\frac{17}{12}P_0$ to $-\frac{1}{12}P_0$, its value midway being $-\frac{7}{24}P_0$; while the longitudinal true stress has the constant value $-\frac{1}{12}P_0$ throughout the cylinder wall. Fig. 31 illustrates the distribution of the tangential and radial true stresses, the former on the right and the latter on the left of the section, the ordinates above the horizontal diameter indicating

tensions and those below it indicating compressions. The figures on the inner, middle and outer ordinates are the true stresses in tons per square inch which would result from an internal pressure of 12 tons per square inch.

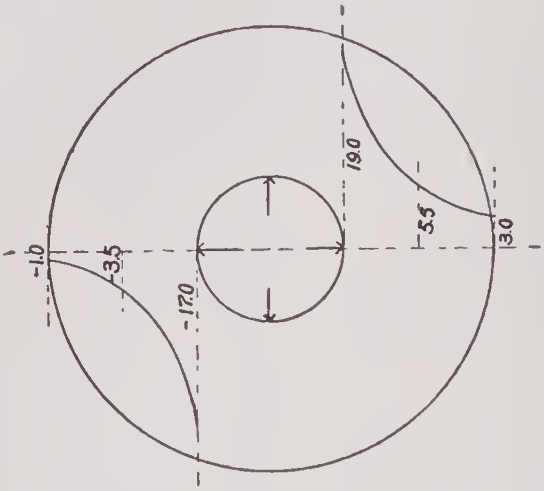


FIG. 31.

201. Case II.—No interior pressure.—Putting $P_0=0$ and $R_n=3R_0$ in (13), (14) and (15), we obtain as the values of the true stresses:

$$\left.\begin{aligned}
&\text{(a)} \quad Ee_t = -\frac{3P_n}{4}\left(1+\frac{2R_0^2}{r^2}\right),\\
&\text{(b)} \quad Ee_p = -\frac{3P_n}{4}\left(1-\frac{2R_0^2}{r^2}\right),\\
&\text{(c)} \quad Ee_q = +\frac{3P_n}{4}.
\end{aligned}\right\} \quad (17)$$

From these it will be seen that as r increases from R_0 to R_n, the circumferential true stress diminishes (algebraically it increases) from $-\frac{9}{4}P_n$ to $-\frac{11}{12}P_n$, its value midway, where $r=2R_0$, being $-\frac{9}{8}P_n$; the radial true stress diminishes from $+\frac{3}{4}P_n$ to $-\frac{7}{12}P_n$, its midway value being $-\frac{3}{8}P_n$; while the longitudinal true stress has the constant value $+\frac{3}{4}P_n$. Fig. 32 illustrates this, the right-hand curve showing the tangential and the left-hand curve the radial true stress at each point in the wall thickness, ordinates above the horizontal diameter indicating tensions and those below it indicating compressions. The figures on the inner, middle and

outer ordinates are the true stresses in tons per square inch which would result from an external pressure of 12 tons per square inch.

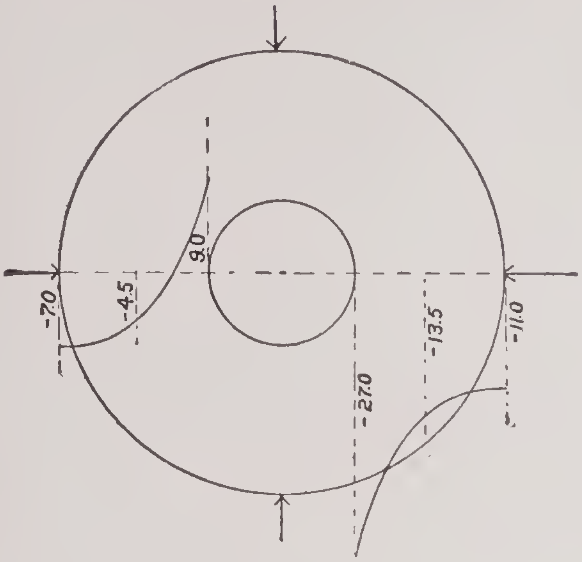


FIG. 32.

202. Case III.—Exterior pressure one-half the interior pressure.—Putting $P_n = \frac{1}{2}P_0$ and $R_n = 3R_0$ in (13), (14) and (15), we obtain as the values of the true stresses:

$$\left.\begin{aligned}
&\text{(a)}\quad Ee_t = +\frac{P_0}{24}\left(18\frac{R_0^2}{r^2} - 7\right).\\
&\text{(b)}\quad Ee_p = -\frac{P_0}{24}\left(18\frac{R_0^2}{r^2} + 7\right).\\
&\text{(c)}\quad Ee_q = +\frac{7}{24}P_0.
\end{aligned}\right\}(18)$$

From these it will be seen that as r increases from R_0 to R_n the circumferential true stress diminishes from $\frac{11}{24}P_0$ to $-\frac{5}{24}P_0$, its value midway being $-\frac{5}{48}P_0$; the radial true stress diminishes (algebraically it increases) from $-\frac{25}{24}P_0$ to $-\frac{9}{24}P_0$, its value midway being $-\frac{23}{48}P_0$; while the longitudinal true stress has the constant value $+\frac{7}{24}P_0$. Fig. 33 illustrates the distribution of the tangential and radial true stresses, the former on the right and the latter on the left of the section, the ordinates above the longi-

tudinal diameter indicating tensions and those below it indicating compressions. The figures on the inner, middle and outer ordinates are the true stresses in tons per square inch which would result from an internal pressure of 12 tons per square inch and an external pressure of 6 tons per square inch.

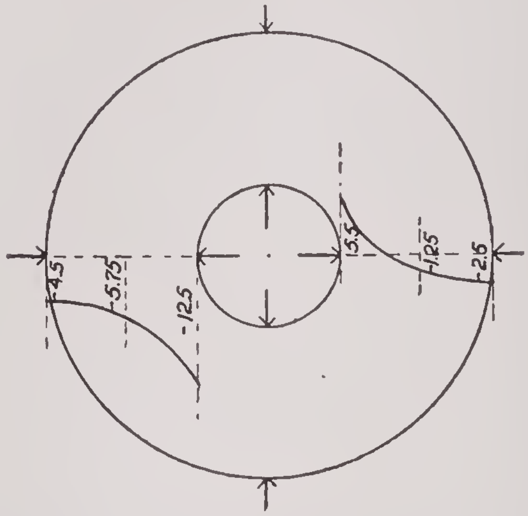


FIG. 33.

203. Comparing Fig. 33 with Figs. 31 and 32, it will be seen that the ordinates of the curves in the former are the algebraic sums of the corresponding ordinates of Fig. 31 and half those of Fig. 32; the stresses due to 12 tons internal and 6 tons external pressure acting together are the same as the algebraic sums of the stresses due to the same pressures acting separately.

204. The strains given by equations (13), (14) and (15) are changes of length per unit length, and since e_p is the radial strain, $c_p \times dr$ is the change of length of dr, and so the whole change of thickness of the cylinder wall is $\int_{R_0}^{R_n} e_p dr$.

Also e_t is the change of length per unit length circumferentially and therefore in a cylinder the change in the length at any circumference will be the length of the circumference multiplied by the change of length per unit length. That is, if Δc is the total change in the length of any circumference of length C, then

$$\Delta c = C \cdot e_t.$$

If r is the radius of the circumference, then $C = 2\pi r$, and substituting this value for C above, we have

$$\Delta c = 2\pi r \cdot e_t.$$

But we also know that $\Delta c = 2\pi \cdot \Delta r$, where Δr is the change in the radius r due to the change in the circumference C caused by Δc. Equating these two values of Δc, we have

$$2\pi \cdot \Delta r = 2\pi r \cdot e_t,$$

or

$$\Delta r = r \cdot e_t,$$

which means that the change of radius at any point whose radius is r must be $r \cdot e_t$.

Therefore the change of the outer radius is $R_n \cdot e_t(R_n)$, and the change in the inner radius is $R_0 \cdot e_t(R_0)$, and the difference between the change in the outer radius and the change in the inner radius must be equal to the *whole change of thickness, i. e.*,

$$\text{Whole change of thickness} = R_n \cdot e_t(R_n) - R_0 \cdot e_t(R_n).$$

But we have an integral expression for the change of thickness, and these two expressions must therefore be equal; therefore

$$\int_{R_0}^{R_n} e_p dr = R_n e_t(R_n) - R_0 e_t(R_0),$$

and it will be found upon trial that this is true of the values of e_p and e_t given by (13) and (14).

205. The hypothesis made in Art. 191 that there is no longitudinal stress is, of course, not true, as a rule, for actual constructions. In the built-up guns, for example, whose strength we are investigating, one end of the bore is closed by a breech block which sustains the internal pressure and thus causes a total longitudinal stress $\pi R_0^2 P_0$ which is distributed over the cross-section of one or more of the cylinders of which the gun is composed. This stress may be taken account of by assuming that it is uniformly distributed, but, as will be shown further on, the hypothesis that q is zero accords as well or better with the facts than any other available one.

EXAMPLES.

(1) Show that in an infinitely thick hollow cylinder ($R_n = \infty$) subjected only to internal pressure (P_0) the true circumferential and radial stresses at the inner surface are of equal value but opposite sign. What are their values? What is the value of the longitudinal stress?

$+\frac{4}{3}P_0$; $-\frac{4}{3}P_0$; 0.

(2) What are the true stresses at the inner surface of an infinitely thick hollow cylinder subjected only to external pressure (P_n)?

$$-2P_n;\ +\tfrac{2}{3}P_n;\ +\tfrac{2}{3}P_n.$$

(3) If the external and internal pressures are equal, what is the state of stress in the cylinder walls?

$$Ec_t = Ec_p = -\tfrac{2}{3}P_0;\ Ec_q = +\tfrac{2}{3}P_0.$$

(4) What would be the change of thickness of a hollow cylinder one diameter thick under internal pressure alone?

$$-\tfrac{5}{6}\,\frac{P_0R_0}{E}.$$

(5) What would be the change of thickness of a hollow cylinder one diameter thick under external pressure only?

$$-\frac{P_nR_0}{2E}.$$

(6) A hollow cylinder half a caliber thick is subjected to an internal pressure of 6 tons per square inch. What is the greatest true stress resulting and where does it occur? What are the true stresses at the outer surface?

$$Ec_t(R_0) = 12 \text{ tons per sq. in.}$$
$$Ec_t(R_n) = 4;\ Ec_p(R_n) = -1\tfrac{1}{3};\ Ec_q = -1\tfrac{1}{3}.$$

(7) If the cylinder of example (6) is only one-quarter of a caliber thick, what are the true stresses at inner and outer surfaces?

$$\left.\begin{aligned} Ec_t(R_0) &= 17\tfrac{3}{5};\ Ec_p(R_0) = -11\tfrac{1}{5} \\ Ec_t(R_n) &= \ \ 9\tfrac{3}{5};\ Ec_p(R_n) = -\ \ 3\tfrac{1}{5} \end{aligned}\right\} Ec_q = -3\tfrac{1}{5}.$$

(8) Show that, as the thickness of wall of a cylinder under internal pressure is made a smaller and smaller fraction of its inner diameter, the circumferential stress becomes more and more nearly constant throughout the wall. If the circumferential stress were constant, what would be the relation between it and the internal pressure?

$$P_0 = \frac{R_n - R_0}{R_0}\,T.$$

(9) A hollow steel tube, radii 3 in. and 6 in., is subjected to an internal pressure of 13 tons per sq. in. Determine the three principal strains at the inner surface. What is the least elastic limit

of the steel which will permit the application of such a pressure without permanent set?

$$e_t(R_0) = .002;\ e_p(R_0) = -.00156;\ e_q = -.00022.$$

26 tons per sq. in.

(10) With the data of example (9) determine the three principal strains at the outer surface of the tube.

$$e_t(R_n) = .00067;\ e_p(R_n) = -.00022;\ e_q = -.00022.$$

(11) Show that the change of wall thickness of a cylinder is independent of the value of the external pressure in the case where the outer radius is twice the inner radius.

$$\text{Change} = -\frac{2P_0R_0}{3E}.$$

Section III.—The Elastic Strength of Simple Hollow Cylinders.

206. We will denote the elastic limit under tension of the material of the cylinder by θ and its elastic limit under compression by ρ. In the case of the forged steel used in modern gun construction, these elastic limits are usually taken to be equal, but with some materials, notably cast iron, ρ is considerably greater than θ, and even in the case of steel it is probable that ρ is always somewhat greater than θ.

In accordance with the principle stated in 188, we consider that the limit of safety is reached whenever either of the principal strains, circumferential, radial or longitudinal, attains the value $\frac{\theta}{E}$ in extension or the value $\frac{\rho}{E}$ in compression; in either case we suppose that the strain ceases to be wholly elastic, and though rupture may not follow, some permanent change of dimensions or distortion will result.

In order, therefore, to determine the maximum pressure which a given cylinder will withstand without permanent set, we have only to equate the greatest strain of extension which results from the pressure to $\frac{\theta}{E}$ and the greatest strain of compression to $\frac{\rho}{E}$ and the least of the pressures given by solving these two equations is the greatest pressure which the cylinder can safely be subjected to. In other words, the limit of the elastic strength of the cylinder

is reached when either the greatest true stress of tension equals the elastic limit of the material under simple tension, or the greatest true stress of compression equal the elastic limit of the material under simple compression. In accordance with Art. 199, we have three cases.

207. Case I.—Internal pressures only.—Putting $P_n=0$ in (13), we obtain

$$Ec_t=\frac{2P_0R_0^2}{3(R_n^2-R_0^2)}\left(1+\frac{2R^2_n}{r^2}\right). \tag{19}$$

This expression is obtained from equation (13) exactly as equation (16a) is obtained, except that no assumption regarding the ratio between R_n and R_0 has been made and hence it is a *General Equation* for this particular case (*i. e.*, no external pressure). [If we substitute in equation (19) the ratio between R_n and R_0 assumed in Art. 199 we will obtain equation (16a), and, similarly, from 199 we can obtain (16b).] Equation (19) is always plus, showing that the circumferential true stress in this case is always tension; and its greatest value is when r has its least value R_0. This shows that the *greatest stress* will be *at the inner surface* (weakest point) and *this maximum stress must not exceed θ.*

Hence we find the value of P_0 which will make the greatest circumferential true stress equal the elastic limit of the material by putting $Ec_t=\theta$ and $r=R_0$ in (19). This gives

$$\theta=\frac{2P_0}{3(R_n^2-R_0^2)}(R_0^2+2R_n^2),$$

from which

$$P_0=\frac{3(R_n^2-R_0^2)}{4R_n^2+2R_0^2}\theta. \tag{20}$$

This expression, having been deduced from equation (13), gives the value of P_0 that will bring the cylinder to its elastic limit of circumferential strain.

We must also find the value of P_0 that will bring the cylinder to its elastic limit of radial strain.

Hence, putting $P_n=0$ in (14), we obtain

$$Ec_p=\frac{2P_0R_0^2}{3(R_n^2-R_0^2)}\left(1-\frac{2R_n^2}{r^2}\right). \tag{21}$$

This is always negative, showing that the radial true stress in this case is always compression; and its greatest value (numeri-

cally) is when $r=R_0$. Hence we find the value of P_0 which will make the greatest radial true stress equal the elastic limit of the material by putting $Ee_p=-\rho$ and $r=R_0$ in (21). This gives

$$-\rho=\frac{2P_0}{3(R_n^2-R_0^2)}(R_0^2-2R_n^2),$$

$$P_0=\frac{3(R_n^2-R_0^2)}{4R_n^2-2R_0^2}\rho. \qquad (22)$$

The determination of the value of the longitudinal true stress is unnecessary, since it can never exceed, and in all practical cases is much less than, one or the other of the other two principal true stresses, the circumferential and the radial.

Now, comparing (20) and (22), since ρ is always equal to or greater than θ, and since the denominator of (20) is greater than the denominator of (22), the value of P_0 given by (20) will always be less than the value of P_0 given by (22). When P_0 reaches the value given by (20), the elastic limit of strain is reached circumferentially, and further increase of P_0 is inadmissible.

Consequently the maximum internal pressure allowable in the case of a simple hollow cylinder under no exterior pressure is given by

$$\mathrm{P}_0=\frac{3(R_n^2-R_0^2)}{4R_n^2+2R_0^2}\theta, \qquad (20\ bis)$$

in which θ is the elastic limit of the material under tension.

Evidently equation (20) gives not only the relation between the maximum allowable internal pressure and the elastic limit of the material, but equally the relation between any internal pressure and the greatest resulting true stress (within the elastic limit).

If any three of the four values θ, R_0, P_0 and R_n be given, (20) may be solved for the fourth value. For example, given all except R_n, then

$$R_n=R_0\sqrt{\frac{3\theta+2P_0}{3\theta-4P_0}}.$$

That is, by means of (20) the necessary thickness of a cylinder to safely withstand a given internal pressure is readily determined. Writing equation (20) in the form

$$\frac{P_0}{\theta}=\frac{3(R_n^2-R_0^2)}{4R_n^2+2R_0^2}$$

and assuming either ratios between the radii to get corresponding ratios between P_0 and θ, or *vice versa*, we can plot a curve showing the proportions that must exist between R_n and R_0 for any given proportion between P_0 and θ, as shown in Fig. 34.

As an example, assuming first that $\frac{R_n}{R_0}=1$, we see that there is no cylinder and hence $\frac{P_0}{\theta}=0$. Again, when $R_n=\infty$, we have

$$\frac{P_0}{\theta}=\frac{3\left(1-\frac{R_0^2}{R_n^2}\right)}{4+\frac{2R_0^2}{R_n^2}},$$

but $R_n=\infty$, therefore

$$\frac{P_0}{\theta}=\frac{3(1-0)}{4+0}=\tfrac{3}{4}.$$

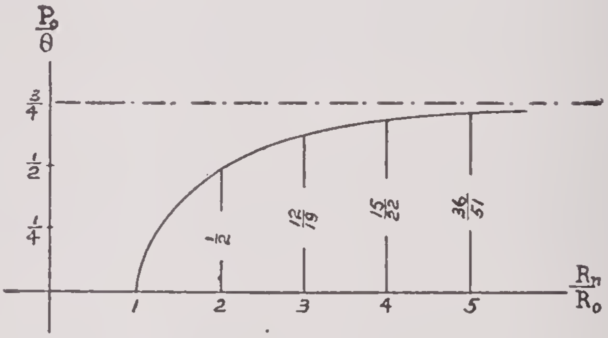


FIG. 34.

Fig. 34 shows how the ratio $\frac{P_0}{\theta}$ increases with the ratio $\frac{R_n}{R_0}$, attaining the maximum value $\frac{3}{4}$ when $\frac{R_n}{R_0}=\infty$, and clearly indicates the small effect upon strength of increasing wall thickness beyond a caliber, that is, when $R_n=3R_0$, wall thickness is

$$3R_0-R_0=2R_0=d=1 \text{ caliber}.$$

208. Examples.—(1) What is the limiting value of the internal pressure which any simple cylinder (regardless of its thickness) will stand without permanent set, the elastic limit of its material being θ? $\frac{3}{4}\theta$.

(2) The walls of a 6-inch steel shell are 1.5 in. thick; if the tensile strength of the steel is 50 tons per sq. in., what powder pressure will burst the shell? 25 tons per sq. in.

(3) What internal pressure will produce a circumferential elongation of .0015 in the case of a simple steel tube of 3 in. interior and 6 in. exterior radius? 9.75 tons per sq. in.

(4) What internal pressure will a cast-steel cylinder of 4 in. internal and 6 in. external radius stand within its elastic limit of 30,000 lbs. per sq. in.? 10,227 lbs. per sq. in.

(5) A nickel-steel cylinder of 7 in. interior radius and 0.5 in. wall thickness has an elastic limit of 70,000 lbs. per sq. in. What internal pressure will it withstand? 4713 lbs. per sq. in.

(6) A cylinder of 7 in. interior diameter has walls 3.5 inches thick. If its elastic limit is 36,000 lbs. per sq. in., what internal pressure will it stand? How much pressure could it withstand if its wall thickness were doubled? if trebled?

18,000; 22,740; 24,550 lbs. per sq. in.

(7) Determine the proper thickness for a cylinder of 6 in. inner radius which is to stand an internal pressure of 3000 lbs. per sq. in., the elastic limit of the material being 28,000 lbs. per sq. in. 0.708 in.

(8) If the radii are 8 in. and 9 in. and the elastic limit is 60,000 lbs. per sq. in., what is the maximum allowable internal pressure? What would it be if the circumferential stress were constant throughout the cylinder walls?

6770; 7500 lbs. per sq. in.

(9) What thickness should a cylinder of 4 in. interior radius have to withstand an internal pressure of 8000 lbs. per sq. in., if the elastic limit is 40,000 lbs. per sq. in.? 0.973 in.

(10) What internal pressure will a cylinder of 6 in. interior radius and 4 in. wall thickness withstand, if the elastic limit is 18 tons per sq. in.? 7.32 tons per sq. in.

209. Case II.—External pressure only.—Putting $P_0=0$ in (13), we obtain

$$Ee_t = -\frac{2P_nR_n^2}{3(R_n^2-R_0^2)}\left(1+\frac{2R_0^2}{r^2}\right),\text{*} \qquad (23)$$

in the same way that (19) is obtained, and is a *General Equation*

* Equations (23) and (25) being *General Equations*, if ratios between R_n and R_0 as assumed in Art. 199 are substituted therein, the specific equations (17a) and (17b) respectively will result.

for this case. This is always negative, showing that the circumferential true stress in this case is always compression; and its greatest value is when $r=R_0$. Hence we find the value of P_n which will make the greatest circumferential true stress equal to the elastic limit of the material by putting $Ee_t=-\rho$ and $r=R_0$ in (23). This gives

$$\rho=\frac{2P_nR_n^2}{R_n^2-R_0^2},$$

$$P_n=\frac{R_n^2-R_0^2}{2R_n^2}\rho. \tag{24}$$

This expression, having been deduced from equation (13), gives the value of P_0 that will bring the cylinder to its elastic limit of circumferential strain. As in the previous case we must also find the value of P_0 that will bring the cylinder to its elastic limit of radial strain.

Hence, putting $P_0=0$ in (14), we obtain

$$Ee_p=-\frac{2P_nR_n^2}{3(R_n^2-R_0^2)}\left(1-\frac{2R_0^2}{r^2}\right).* \tag{25}$$

Equation (25) is positive when $r=R_0$ and continues so until r attains the value $R_0\sqrt{2}$, beyond which point it becomes negative; its greatest numerical value, however, is when $r=R_0$. Hence, to find the value of P_n which would make the greatest radial true stress equal the elastic limit of the material, we would put $Ee_p=\theta$ and $r=R_0$ in (25). A comparison of (25) with (23), however, will show that, for every value of r, Ee_t is greater than Ee_p, so that the elastic strength of the cylinder depends upon its resistance to circumferential stress and not upon its resistance to radial stress.†

Consequently the maximum external pressure allowable in the case of a simple hollow cylinder under no interior pressure is given by

$$P_n=\frac{R_n^2-R_0^2}{2R_n^2}\rho \tag{24 bis}$$

in which ρ is the elastic limit of the material under compression.

* See footnote, page 189.

† With a material like cast iron, of which the elastic limit of compression greatly exceeds that of tension, the limit of elastic strain radially (in this case extension) may in some cases be reached before the limit of elastic strain circumferentially (in this case compression) is attained.

Fig. 35 shows the increase of the ratio $\frac{P_n}{p}$ as wall thickness increases, and clearly indicates how little is gained by going beyond a thickness of one caliber.

This curve is plotted from equation (24) in the same way Fig. 34 is obtained from (20).

Of course (24) expresses the relation between the external pressure and the greatest resulting true stress within as well as at the limit of elastic strain.

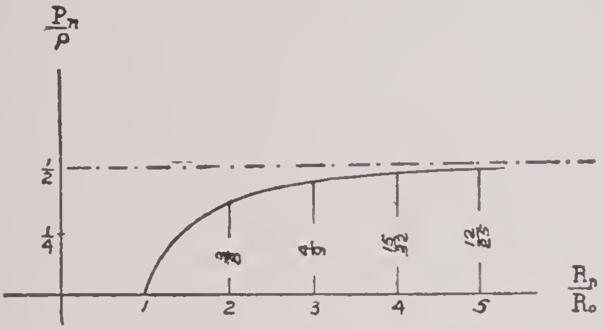


FIG. 35.

210. Examples.—(1) What is the limiting value of the external pressure which any simple hollow cylinder, regardless of its thickness, can withstand without permanent set, the elastic limit of compression being ρ? $\frac{1}{2}\rho$.

(2) What external pressure can a tube of 7.5 in. interior radius and 1.75 in. thickness of wall withstand, the elastic limit for compression being 30,000 lbs. per sq. in.? 5139 lbs. per sq. in.

(3) How thick should the tube of example (2) ($R_0=7.5$ in.) be to withstand an external pressure of 10,000 lbs. per sq. in.? 5.49 in.

(4) The inner and outer radii of a steel tube are 4 in. and 7 in., and it is to be subjected to an external pressure of 8.3 tons per sq. in. What are the circumferential and radial strains at the inner surface? What is the greatest true stress?

$-.001897$; $+.000632$; 24.65 tons per sq. in.

(5) How thick should the walls of a 6-inch shell be to withstand 6 tons per sq. in. external pressure, without passing the elastic limit of compression of 18 tons per sq. in. 1.27 in.

(6) What external pressure will a cylinder of 6 in. interior radius and 4 in. wall thickness withstand, if the elastic limit is 18 tons per sq. in.? 5.76 tons per sq. in.

(7) What wall thickness should a cylinder have to withstand 8000 lbs. per sq. in. external pressure, the interior radius being 4 in. and the elastic limit 40,000 lbs. per sq. in.? 1.16 in.

(8) If the interior radius is 8 in., the wall thickness 1 in., and the elastic limit 60,000 lbs. per sq. in., what is the maximum allowable external pressure? What would it be if the circumferential stress were constant throughout the walls?

6297; 6667 lbs. per sq. in.

211. Case III.—Both internal and external pressure.—In this case there are two main subdivisions; (a) when the exterior pressure exceeds the interior pressure, and (b) when the interior pressure exceeds the exterior.

Furthermore, there are two subdivisions under (b), making a total of three possible solutions.

In Art. 202 the expressions deduced are for a specific case, with definite ratios of radii. Here we deduce *General Expressions,* whereas equations (18) a, b and c are specific for the conditions stated in Art. 202. Which of the true stresses first reaches the elastic limit depends, in this case, upon the relation between the two pressures, and we must consider the three possible cases separately.

(a) We first consider the case where

$$P_n > P_0, \text{ hence } P_n R_n^2 > P_0 R_0^2.$$

Looking at (13), since $P_n R_n^2$ is greater than $P_0 R_0^2$ we see at once that both terms of (13) are negative, showing that the circircumferential true stress is always compression; and its greatest numerical value is when r has its least value R_0. On the other hand, the two terms of the value of Ee_p, equation (14), have opposite signs, showing that the radial true stress may be either tension or compression, according to which term preponderates, and also showing that at each point Ee_t is greater numerically than Ee_p. We therefore obtain an equation between the value of P_0 and P_n which will make the greatest true stress resulting from their concurrent action equal the elastic limit of the material by putting $Ee_t = -\rho$ ($-\rho$ because, as we found above, the terms will be negative, showing the stress to be compressive) and $r = R_0$ in (13) This gives

$$\rho = \frac{6P_n R_n^2 - 2P_0 R_0^2 - 4P_0 R_n^2}{3(R_n^2 - R_0^2)},$$

$$P_0 = \frac{6P_n R_n^2 - 3(R_n^2 - R_0^2)\rho}{4R_n^2 + 2R_0^2}. \tag{26}$$

Consequently, *when P_n exceeds P_0*, the relation between the internal pressure and the maximum allowable external pressure is given by (26), in which ρ is the elastic limit under compression.

(b) We next consider the case where

$$P_0 > P_n \text{ but } P_0R_0^2 < P_nR_n^2.$$

$P_0R_0^2$ is less than $P_nR_n^2$ owing to the fact that P_0 is not great enough to overcome the excess of R_n^2 over R_0^2.

In this case the first term of the value of Ee_t, equation (13), remains negative, while the second term is positive, so that the circumferential true stress may be either tension or compression, according to which term preponderates. But both terms of the value of Ee_p, equation (14), are now negative, showing that the radial true stress is always compression and is numerically greater than Ee_t at each point; moreover, the maximum numerical value of Ee_p is when r has its least value R_0. We therefore obtain an equation between the values of P_0 and P_n which will make the greatest true stress resulting from their concurrent action equal to the elastic limit of the material by putting $Ee_p = -\rho$ and $r = R_0$ in (14). This gives

$$\rho = \frac{P_0(4R_n^2 - 2R_0^2) - 2P_nR_n^2}{3(R_n^2 - R_0^2)},$$

$$\theta = \frac{3(R_n^2 - R_0^2)\rho + 2P_nR_n^2}{4R_n^2 + 2R_0^2}. \tag{27}$$

Consequently, *when P_0 exceeds P_n but at the same time $P_0R_0^2$ is less than $P_nR_n^2$*, the maximum allowable internal pressure is given by (27), in which ρ is the elastic limit of the material under compression.

(c) Lastly, we consider the case where

$$P_0 > P_n \text{ and } P_0R_0^2 > P_nR_n^2.$$

Here P_0 is great enough, together with R_0^2, to overcome the excess of R_n^2 over R_0^2.

In this case both terms of the value of Ee_t, equation (13), are positive, showing that the circumferential true stress is always tension; its greatest value occurs when $r = R_0$; and at each point it is numerically greater than Ee_p since the two terms which make up the latter's value are now of different signs. That is, Ee_t from equation (13) is numerically greater than Ee_p from equation (14)

if the same internal pressure, P_0, is used in both equations. Therefore a smaller P_0 is required to produce a circumferential true stress, θ, in equation (13), than is required to produce a radial true stress, ρ, in equation (14) equal to or greater than θ. We therefore obtain an equation between the value of P_0 and P_n which will make the greatest true stress resulting from their concurrent action equal the elastic limit of the material by putting $Ee_t = \theta$ and $r = R_0$ in (13). This gives

$$\theta = \frac{P_0(4R_n^2 + 2R_0^2) - 6P_nR_n^2}{3(R_n^2 - R_0^2)},$$

$$P_0 = \frac{3(R_n^2 - R_0^2)\theta + 6P_nR_n^2}{4R_n^2 + 2R_0^2}. \tag{28}$$

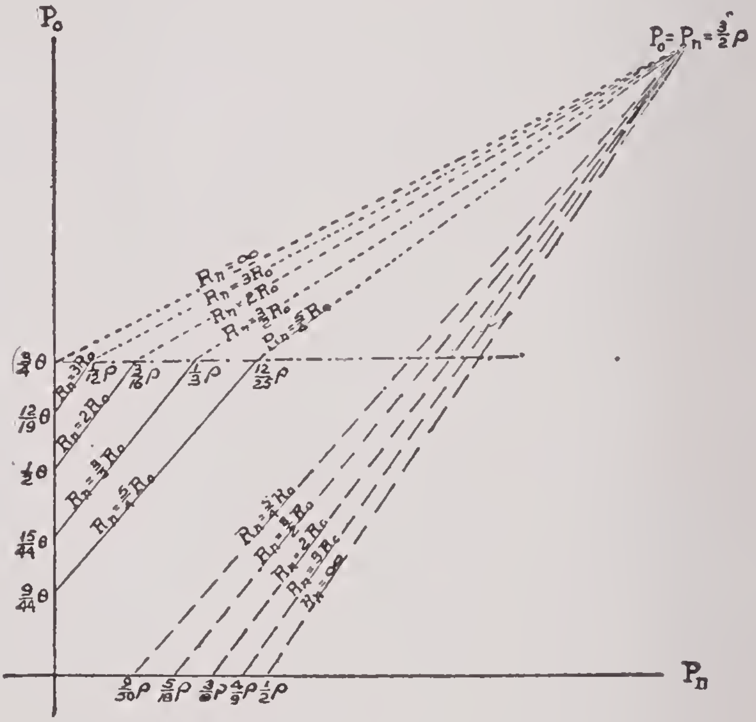


FIG. 36.

Consequently, *when P_0 exceeds P_n and at the same time $P_0R_0^2$ exceeds $P_nR_n^2$*, the maximum allowable internal pressure is given by (28), in which θ is the elastic limit of the material under tension.

Of course equations (26), (27) and (28), each under its appropriate conditions, express the relation between the internal pressure, the external pressure and the greatest resulting true stress within the elastic limit as well as at that limit.

212. The relation between simultaneous values of P_0 and P_n which will just bring a given cylinder to the limit of its elastic strength may be graphically shown by drawing the three straight lines represented by equations (26), (27) and (28). In Fig. 36, values of P_0 are represented by the ordinates, and corresponding values of P_n by the abscissæ, and the cases of five different thicknesses of cylinder wall are illustrated.

213. Taking equation (26), which is the expression of Case IIIa, and assuming now a radii ratio $R_n = 2R_0$ we find (26) reduces to the form

$$P_0 = \frac{24P_n - 9}{18}, \tag{a}$$

which is a simple equation between simultaneous values of P_n and P_0 for the assumed radii ratio.

Case IIIa is based on the fact that $P_n > P_0$. Hence, putting $P_0 = 0$ in the equation above we find $P_n = \frac{3}{8}\rho$, which point we plot.

Now, as Case IIIa approaches Case IIIb, that is, as P_n and P_0 become more and more nearly equal, we approach a point where P_n will be equal to P_0 and from this point P_0 will begin to be greater than P_n and we will have the condition of Case IIIb. Therefore the transition point between Case IIIa and Case IIIb occurs when $P_n = P_0$.

Hence, substituting $P_0 = P_n$ in equation (a) above, we find

$$18P_n = 24P_n - 9\rho,$$

or

$$P_n = \tfrac{3}{2}\rho = P_0.^*$$

We plot this point and, as equation (a) evidently expresses a straight line, by joining the two points (*i. e.*, $P_0 = 0$, $P_n = \frac{3}{8}\rho$; and $P_n = P_0 = \frac{3}{2}\rho$) we have the graph showing the simultaneous values between P_n and P_0 when $R_n = 2R_0$.

Case IIIb states that $P_0 > P_n$, but P_0 must begin to be greater than P_n from a point where $P_n = P_0$. But the point $P_n = P_0 = \frac{3}{2}\rho$ is the transition point from Case IIIa to Case IIIb. Hence, first substituting in equation (27) the assumed radii ratios, we find (27) reduces to

$$P_0 = \frac{9\rho + 8P_n}{14}, \tag{b}$$

* Although the point $P_n = P_0 = \frac{3}{2}\rho$ is here determined for the condition $R_n = 2R_0$, it will be found that this point will be the same for all radii ratios.

which is a simple equation between simultaneous values of P_n and P_0 for the assumed radii ratio.

We must plot the graph of this equation from the point where $P_n=P_0$, *i. e.*, the transition point from Case IIIa to Case IIIb. Therefore, substituting $P_n=P_0$ in equation (b) above, we find

$$P_n=P_0=\frac{9\rho+8P_0}{14},$$

or

$$P_0=\tfrac{3}{2}\rho=P_n,$$

which we see is exactly the same value given for the graph equation (26) and consequently Case IIIb is a direct continuation of Case IIIa.

Now as P_n decreases we approach the condition of a cylinder under interior pressure only, which is the condition of Case I given in Art. 207, and we know from that article that P_0 cannot exceed $\frac{3}{4}\theta$ when $P_n=0$ even if $R_n=\infty$.

P_n in Case IIIb will not be zero, but it may be very small, so we may safely substitute $P_0=\frac{3}{4}\theta$ in equation (b) to see how large P_n must be owing to the fact that R_n does not equal ∞, but the definite value $2R_0$.

Therefore, substituting $P_0=\frac{3}{4}\theta$ and remembering that $\theta=\rho$ (for steel) in equation (b), we find $P_n=\frac{3}{16}\rho$.

We plot the two points (*i. e.*, $P_n=P_0=\frac{3}{2}\rho$; and $P_0=\frac{3}{4}\theta$, $P_n=\frac{3}{16}\rho$) and knowing from its form that equation (b) is a straight line, by joining the points we have a graph of Case IIIb.

Now we see that in equation (28) when P_n attains the value $\frac{3R_0^2}{4R_n^2}\theta$, P_0 has the value $\frac{3}{4}\theta$, regardless of the thickness of the cylinder, and with these values of the pressures the inner surface of the cylinder is both at its elastic limit of extension circumferentially and at its elastic limit of compression radially.

Further increase of P_0 is allowable if P_n be also increased, but from the point where $P_0=\frac{3}{4}\theta$ the relation between P_0 and P_n is given by (27), and hence this value of $P_0=\frac{3}{4}\theta$ is the transition point (or line in this case) between Case IIIb and Case IIIc.

We therefore now take equation (28) and first substitute our assumed radii ratios, reducing equation (28) to the form

$$P_0=\frac{9\theta+24P_n}{18}, \qquad \text{(c)}$$

which is a simple equation between simultaneous values of P_n and P_0 for the assumed radii ratios.

Starting with the value of $P_0=\frac{3}{4}\theta$, the transition value, we find $P_n=\frac{3}{16}\theta=\frac{3}{16}\rho$, $(\theta=\rho)$ and this is the same point at which we found equation (27) to terminate on the $P_0=\frac{3}{4}\theta$ line, and hence Case IIIc meets and is a direct continuation of Case IIIb.

Again substituting $P_n=0$ in equation (c) we find $P_0=\frac{1}{2}\theta$, and as equation (c) expresses a straight line we join the two points (*i. e.*, $P_0=\frac{3}{4}\theta$, $P_n=\frac{3}{16}\rho$; and $P_0=\frac{1}{2}\theta$, $P_n=0$) which gives the graph of Case IIIb.

214. Fig. 36 shows the graphs obtained from equations (26), (27) and (28) for the radii ratios assumed above, and for four other ratios, these being drawn in the same way as the example taken (*i. e.*, for $R_n=2R_0$), not that these five relations are the only ones possible but that they are simply five examples here shown.

The relative values of P_0 (ordinates) and P_n (abscissæ) are plotted to scale. Therefore, given any value of P_0 or P_n, the equations that should be used to find P_n or P_0 are indicated.

215. Cases I, II and the subdivisions under Case III are all applicable to a built-up gun simultaneously.

The outer layer of a gun is always under the stresses shown by equation (19), both at rest and in action. The inner tube of the gun is under the stress of Case II, equation (23), in the state of rest. The layers of the gun intermediate between the tube and the outer layer are under the stresses of the three subdivisions of Case III, as is the tube in the state of action. Which one of the subdivisions of Case III to use depends upon the relations between P_n and P_0 and the radii ratios.

(26) represents the greatest value of P_n while P_0 is reduced in value.

(27) represents the relation between P_0 and P_n as we go beyond the value $\frac{3}{4}\theta$ for P_0.

(28) represents the relation between P_n and P_0 as long as P_0 is $\frac{3}{4}\theta$ or less.

In one case only are all three equations used and that is when P_0 has the value $\frac{3}{4}\theta$. In this case the conditions of all three equations are fulfilled but as would be expected we find the values derived from (27) and (28) are the same.

An example or two will suffice to complete the explanation. Suppose we take example 2, Art. 216, here $P_n=\rho$. From what has been said before and by looking at Fig. 36 we see that a line erected parallel to the ordinate from a point on the abscissæ cuts both (27) and (26); we have the two values and from what has gone before we would expect the maximum value of P_0 to come from (27) and the minimum from (26).

Example 5, Art. 216: $\frac{P_n}{\theta}=\frac{5000}{30000}$ or $\rho=\frac{1}{6}$.

Here we find that our line cuts (28) and (27); but as the two relations are not the same, P_n is not increased so P_0 is not increased, (28) is our only solution.

Example 6, Art. 216: $\frac{P_0}{\theta}=\frac{10000}{70000}=\frac{1}{7}$. Our line this time parallel to the abscissæ cuts only (26).

Example 7, Art. 216: $\frac{P_0}{\theta}=\frac{20000}{36000}=\frac{5}{9}$.

Our line parallel to the abscissa cuts both (26) and (28), hence there are two solutions and two external pressures.

216. Examples.—(1) If $R_n=2R_0$ and $P_n=\rho=\theta$, what is the greatest and what the least allowable value of P_0?

$\frac{17}{14}\rho$; $\frac{5}{6}\rho$.

(2) If $R_n=\frac{5}{4}R_0$ and $P_n=\rho$, what are the greatest and least allowable values of P_0?

$\frac{77}{68}\rho$; $\frac{41}{44}\rho$.

(3) If $R_n=\frac{3}{2}R_0$, what value must P_n have in order that P_0 may have the value of $\frac{3}{4}\theta$?

$\frac{1}{3}\theta$ or $\frac{8}{9}\theta$.

(4) If $R_n=\frac{5}{4}R_0$, what value must P_n have in order that P_0 may have the value $\frac{3}{4}\theta$?

$\frac{12}{25}\theta$ or $\frac{21}{25}\theta$.

(5) What internal pressure will a cast-steel cylinder of 4 in. interior and 6 in. exterior radius stand within its elastic limit of

30,000 lbs. per sq. in. if it is under an external pressure of 5000 lbs. per sq. in.? 16,363 lbs. per sq. in.

(6) A nickel-steel cylinder of 7 in. interior radius and 1.5 in. wall thickness has an elastic limit of 70,000 lbs. per sq. in. What external pressure will it withstand if it is under an internal pressure of 10,000 lbs. per sq. in.? 20,190 lbs. per sq. in.

(7) The inner and outer radii of a steel tube are 4 in. and 7 in.; what external pressure will enable it to withstand an internal pressure of 20,000 lbs. per sq. in. if the elastic limit of the steel is 36,000 lbs. per sq. in.? 3390 to 27,630 lbs. per sq. in.

Section IV.—The Elastic Strength of Compound Cylinders.

217. A reference to Fig. 31 will show that the outer portions of a thick simple cylinder play but a small part in resisting internal pressure. A *compound cylinder* is one formed by the superposition of simple cylinders, the object being to utilize to the utmost the contractile power of the outer parts and thus to increase the resistance to internal pressure beyond what it would be if the entire mass were in one piece.

If the elementary cylinders are of the same material, or have equal moduli of elasticity, they must be assembled so that each exerts an initial pressure upon the one within it. This is accomplished by making the interior diameter of each elementary cylinder (before it is put in place) less than the exterior diameter of the cylinder upon which it is to be superposed by a certain quantity which is called the *shrinkage*. A compound cylinder so assembled is said to be under *initial tension*.

If the elementary cylinders are of different materials, and are so arranged that the modulus of elasticity of each is greater than that of the one within it, they may be assembled without shrinkage. Such a cylinder is called a compound cylinder of *variable elasticity*.*

* Modulus of elasticity is inversely proportional to the elasticity or allowable strain, for $E = \frac{p}{e}$, or E is inversely proportional to e. For example, if we have two cubes, one rubber and one steel, and on each we place equal heavy weights, the strains in the rubber will be greater than in the steel though both are under the same stress; therefore the fraction $\frac{p}{e}$ is much smaller for rubber (e being greater) than for steel and hence the E's vary inversely as the e's. Thus we see why the most elastic material must be placed next to the bore.

These two principles of variable elasticity and of initial tension were formerly often employed in combination, the commonest examples being cast-iron guns with reinforcing hoops of steel, but in modern gun construction, excepting for certain bronze field pieces, steel is now used to the exclusion of other metals, and the principle of initial tension is universally adopted.*

218. In the investigation of the elastic strength of a compound cylinder, it is necessary to consider its state of strain both when the maximum internal pressure is acting and when the internal pressure is zero: the first of these two conditions is called the *state of action* and the second is called the *state of rest.*

In the state of action each cylinder except the outer one is subjected to two pressures, one internal and the other external, while the outer cylinder is subjected to internal pressure only, atmospheric pressure being neglected on account of its insignificant value as compared with the other forces.

In the state of rest the inner cylinder is under external pressure only, the outer cylinder is under internal pressure only, and each of the intermediate cylinders is subjected to both an internal and an external pressure.

219. We adopt the following nomenclature:

R_0 and R_1 are the inner and outer radii of the innermost or first elementary cylinder, R_1 and R_2 of the next, ..., R_{n-1} and R_n of the outermost or nth.

θ_0 and ρ_0, θ_1 and ρ_1, ...θ_n and ρ_n are the elastic limits of the material of the elementary cylinders in the same order, from the 1st to the nth; and E is their common modulus of elasticity.

P_0, P_1, ...P_n are the radial stresses in the state of action at the successive surfaces of the elementary cylinders, and $\bar{P}_0$, $\bar{P}_1$, ...$\bar{P}_n$ are the radial stresses at the same surfaces in the state

* Rodman was to some degree successful in applying the principle of initial tension to solid guns, the cast-iron smooth-bore guns known by his name having been cast hollow and cooled from the interior with the object of securing compression of the bore and tension of the outer parts of the finished gun; and the application of essentially the same process to steel guns, either cast or forged in one piece, has been shown to be feasible and advantageous.

of rest; they are always plus, excepting that $\bar{P}_0$, P_n and $\bar{P}_n$, being only atmospheric pressures, are considered to be zero.*

T_0, T_1, ...T_n are the circumferential stresses in the state of action, and $\bar{T}_0$, $\bar{T}_1$, ...$\bar{T}_n$ are the circumferential stresses in the state of rest, at the successive surfaces whose radii are R_0, R_1, ...R_n; they are plus when tensions and minus when compressions.

$e_p(R_0)$, $e_p(R_1)$, ...$e_p(R_n)$ are the radial strains, and $e_t(R_0)$, $e_t(R_1)$, ...$e_t(R_n)$ are the circumferential strains at radii R_0, R_1, ...R_n, in the state of action; the same symbols with a dash over each, as $\bar{e}_p(R_0)$, are the corresponding strains in the state of rest; they are all plus when lengthenings and minus when shortenings.

Since the states of stress and strain on either side of the surface of contact of two elementary cylinders may be different (must be if they were assembled with shrinkage), it is necessary to distinguish between them. A prime mark over any letter or symbol indicates that it refers to the outer of the two surfaces which are united by the contact. Thus T_1' is the tension at the inner surface of the second cylinder as distinguished from T_1 which is the tension at the outer surface of the first cylinder; $e_p(R_2')$ is the radial strain in the outer of the two surfaces which meet at R_2; $Ee_t(R_1')$ and $Ee_t(R_1)$ are the circumferential true stresses in the outer and inner of the two surfaces which meet at R_1; and so on. (At R_0 and R_n no prime marks are needed, as there is but one surface at each.)

p_0, p_1, ...p_n are the simultaneous changes in the radial pressures P_0, P_1, ...P_n resulting from any cause, for example, as the cessation of the internal pressure P_0.

220. Evidently, with any given assemblage of elementary cylinders, the elastic strength to resist internal pressure will be greatest when in the state of action each cylinder is strained to its elastic limit. Moreover, in a compound cylinder so assembled that all the elementary cylinders reach their elastic limits of strain simultaneously under the action of the internal pressure P_0, that pressure must be greater than the pressure P_1 which acts at the surface

* This convention that radial stresses which are compressive shall be called positive, is explained in 190; it must be remembered, however, that a radial strain, like all other strains, is called minus when it denotes a decrease of length.

of contact of the two innermost elementary cylinders; and the pressures at the different surfaces of contact must diminish successively, P_1 being greater than P_2, P_2 greater than P_3, and so on; for the reason that each of these pressures is balanced by the contractile force of only that part of the compound cylinder which is outside of it.

We will first consider a compound cylinder composed of two elementary cylinders so assembled that each reaches the limit of its elastic strength when the internal pressure P_0 acts.

Then, since the outer cylinder is at its elastic limit of strain under the sole action of an internal pressure P_1, we have, applying Eq. (20),

$$P_1 = \frac{3(R_2^2 - R_1^2)}{4R_2^2 + 2R_1^2}\,\theta_1. \qquad (29)$$

And, since the inner cylinder is at its elastic limit of strain under the joint action of an internal pressure P_0 and an external pressure P_1, of which pressures P_0 is the greater, we have, applying (27) and (28), either

$$P_0(\rho) = \frac{3(R_1^2 - R_0^2)\rho_0 + 2P_1R_1^2}{4R_1^2 - 2R_0^2}, \qquad (30)$$

or

$$P_0(\theta) = \frac{3(R_1^2 - R_0^2)\theta_0 + 6P_1R_1^2}{4R_1^2 + 2R_0^2}, \qquad (31)$$

of which (30) gives the value of P_0 which will bring the inner surface to its elastic limit of strain by *radial compression*, while (31) gives the value of P_0 which will bring the inner surface to its elastic limit of strain by *circumferential extension*. The least of these two values of P_0 is the true value of the maximum allowable internal pressure, but, since which will be the least depends upon the values of P_1, R_0 and R_1, we have to express both values, and we therefore distinguish between them as shown.

221. Having ascertained what maximum internal pressure our assumed compound cylinder will safely withstand, we have next to determine its condition when the internal pressure is removed, for no part of it must be overstrained either in the state of action or in the state of rest.

The state of rest differs from the state of action solely in the cessation of P_0; this must reduce P_1, and consequently the outer cylinder, which is subjected to no other pressure than P_1, must be

under less strain after the removal of P_0 than while it acts; the inner cylinder, however, while under a less external pressure, is no longer supported by P_0 and so may be under greater strain in the state of rest than it was in the state of action. To determine whether this be so, we must find the value of the external pressure to which the inner cylinder is subjected after P_0 has been removed.

Putting $r=R_1$ in (13), we obtain for the value of the circumferential strain at the outer surface of the inner cylinder (R_n and P_n becoming R_1 and P_1 in this case)

$$e_t(R_1)=\frac{1}{E}\left[\frac{6P_0R_0^2-P_1(4R_0^2+2R_1^2)}{3(R_1^2-R_0^2)}\right]. \tag{32}$$

Also, remembering that the radii of the outer cylinder are R_1 and R_2, and that it is subjected only to an internal pressure P_1, we obtain for the value of the circumferential strain at the inner surface of the outer cylinder

$$e_t(R_1')=\frac{1}{E}\left[\frac{P_1(2R_1^2+4R_2^2)}{3(R_2^2-R_1^2)}\right]. \tag{33}$$

These equations, giving the strains caused by the pressures P_0 and P_1, will also give the changes of strain resulting from simultaneous changes of the pressures (p_0 and p_1). But the surfaces of contact of the elementary cylinders must contract and expand together, and so the change of circumferential strain at the outer surface of the inner cylinder must equal that which simultaneously occurs at the inner surface of the cylinder embracing it. Hence, substituting p_0 for P_0 and p_1 and P_1 in the second numbers of (32) and (33), and equating them, we obtain the following relation between simultaneous changes of pressure at $r=R_0$ and $r=R_1$:

$$\frac{6p_0R_0^2-p_1(4R_0^2+2R_1^2)}{3(R_1^2-R_0^2)}=\frac{p_1(2R_1^2+4R_2^2)}{3(R_2^2-R_1^2)}$$

$$3p_0R_0^2(R_2^2-R_1^2)=3p_1R_1^2(R_2^2-R_0^2),$$

$$p_1=\frac{R_0^2(R_2^2-R_1^2)}{R_1^2(R_2^2-R_0^2)}\,p_0. \tag{34}$$

Any change of pressure (p_0) at the inner surface, where $r=R_0$, will cause the change of pressure (p_1) at the surface of contact, where $r=R_1$, given by (34); and, *vice versa*, any change p_1 will cause the change p_0, given by (34). Therefore, putting $p_0=-P_0$ in (34), we have the change in P_1 which results from the suppres-

sion of the internal pressure P_0, and so $\bar{P}_1 = P_1 - \frac{R_0^2(R_2^2-R_1^2)}{R_1^2(R_2^2-R_0^2)} P_0$ is the external pressure to which the inner cylinder is subjected in the state of rest, and this must not exceed $\frac{R_1^2-R_0^2}{2R_1^2} \rho_0$, which has been shown in Art. 209 to be the greatest external pressure which, acting alone on the cylinder, is allowable.

222. The shrinkage.—The excesses of the exterior diameters of the elementary cylinders, before assemblage, over the interior diameters of the cylinders which are to embrace them are called the *shrinkages*, and are designated by S_1, S_2, S_3, etc., S_1 being the shrinkage of the cylinder whose interior radius is R_1, S_2 that of the cylinder whose interior radius is R_2, etc.* The differences of diameter per unit of diameter, $\frac{S_1}{2R_1}$, $\frac{S_2}{2R_2}$, $\frac{S_3}{2R_3}$, etc., are called the *relative shrinkages*, and are designated by ϕ_1, ϕ_2, ϕ_3, etc.

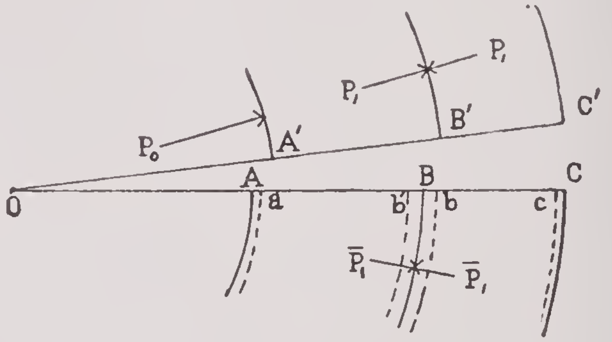


FIG. 37.

Referring to Fig. 37, Oa and Ob represent the inner and outer radii of the inner of two elementary cylinders, and Ob' and Oc the inner and outer radii of the outer one, before assembling, so that $2b'b = S_1$ is the shrinkage; while OA, OB and OC represent the inner radius (R_0), the radius of the surface of contact (R_1) and the outer radius (R_2) after assemblage. When the internal pressure P_0 acts, the compound cylinder is expanded, the three radii becoming OA', OB' and OC', respectively, and, by hypothesis, in this state the inner surface of the outer cylinder is under the circumferential true stress θ_1; *i. e.*, its circumferential strain is $\frac{\theta_1}{E}$.

* The shrinkages are so small in comparison with the radii that it is unnecessary to distinguish $R_1 \pm S_1$ from R_1, $R_2 \pm S_2$ from R_2, etc., in the various formulas.

But the change of the inner radius of the outer cylinder from its free state to the state of action is $OB'-Ob'$; therefore $OB'-Ob'=\frac{R_1\theta_1}{E}$. And the change of the outer radius of the inner cylinder from its free state to the state of action is $OB'-Ob$, and this, by (32), is

$$R_1c_t(R_1)=\frac{R_1}{E}\left[\frac{6P_0R_0^2-P_1(4R_0^2+R_1^2)}{3(R_1^2-R_0^2)}\right].$$

Hence

$$S_1=2b'b=2[OB'-Ob'-(OB'-Ob)]$$

is given by

$$S_1=\frac{2R_1}{E}\left[\theta_1-\frac{6P_0R_0^2-P_1(4R_0^2+2R_1^2)}{3(R_1^2-R_0^2)}\right]. \tag{35}$$

223. The formulas which we have deduced for this case of a compound cylinder composed of but two elementary cylinders are grouped together in (36).

$$\left.\begin{aligned}
&\text{(a)} & P_1&=\frac{3(R_2^2-R_1^2)}{4R_2^2+2R_1^2}\theta_1.\\
&\text{(b)} & P_0(\theta)&=\frac{3(R_1^2-R_0^2)\theta_0+6P_1R_1^2}{4R_1^2+2R_0^2},\\
&\text{(b}'\text{)} & P_0(\rho)&=\frac{3(R_1^2-R_0^2)\rho_0+2P_1R_1^2}{4R_1^2-2R_0^2}.\\
&\text{(c)} & P_1\left(=P_1-\frac{R_0^2(R_2^2-R_1^2)}{R_1^2(R_2^2-R_0^2)}P_0\right)&<\frac{R_1^2-R_0^2}{2R_1^2}\rho_0{}^*.\\
&\text{(d)} & S_1&=\frac{2R_1}{E}\left[\theta_1+\frac{P_1(4R_0^2+2R_1^2)-6P_0R_0^2}{3(R_1^2-R_0^2)}\right].
\end{aligned}\right\} \tag{36}$$

To apply these formulas, calculate P_1 and the two values of P_0 by (a), (b) and (b′), using for θ_1, θ_0 and ρ_0 the elastic limits of the material as determined in the testing machine; then, with P_1 and the least of the two values of P_0, determine whether the condition required by (c) is fulfilled; if it is, calculate S_1 with the same values of P_1 and P_0; if it is not, find new values of P_1 and P_0, using the same values of θ_0 and ρ_0 but a value of θ_1 sufficiently less

* Note that the expression in (36c) following the sign < is equation (24) in Art. 209 when the definite radius R_1 is substituted for the general radius R_n; that is, it is the maximum $\bar{P}_1$. Naturally the value of $\bar{P}_1$ obtained from the expression to the left of the sign must not exceed the maximum pressure that a cylinder under external pressure only may stand, hence this test.

than the first value assigned it to cause the condition of (c) to be met.

224. As an example, we will determine the strength of a compound cylinder of steel for which $R_0=3$ in., $R_1=5$ in., $R_2=8$ in., $\theta_1=24$ tons per sq. in., and $\theta_0=\rho_0=18$ tons per sq. in.

$$P_1=\frac{3(64-25)}{256+50}\times 24=9.18,$$

$$P_0(\theta)=\frac{3(25-9)\times 18+6\times 25\times 9.18}{100+18}=18.99,$$

$$P_0(\rho)=\frac{3(25-9)\times 18+2\times 25\times 9.18}{100-18}=16.13.$$

An internal pressure of 16.13 tons per sq. in. will bring the radial strain of the inner surface to the elastic limit, and so this is the greatest safe pressure, although the circumferential strain does not reach the elastic limit unless the internal pressure is raised to 18.99 tons per sq. in. We therefore proceed to see if the condition of equation (c) is met with the values $P_1=9.18$, $P_0=16.13$.

$$9.18-\frac{9(64-25)}{25(64-9)}\times 16.13<\frac{25-9}{50}\times 18,$$

$$9.18-4.12<5.76,$$

$$5.06<5.76.$$

The external pressure on the inner cylinder in the state of rest is 5.06 tons per sq. in., while it is capable of withstanding 5.76 tons per sq. in. Therefore the values $P_1=9.18$ and $P_0=16.13$ are allowable, and we proceed to determine the shrinkage.

$$S_1=\frac{10}{13000}\left[24+\frac{9.18(36+50)-6\times 16.13\times 9}{3(25-9)}\right],$$

$$S_1=\frac{10}{13000}\left[24-1.699\right]=.01715.$$

The inner diameter of the outer cylinder must be bored to a diameter .01715 inches less than the outer diameter of the inner cylinder, and, if assembled with this shrinkage, the compound cylinder can be safely subjected to the internal pressure 16.13 tons per sq. in.

225. If the shrinkage used in assembling the compound cylinder be known, the resulting strains and elastic strength are determined as follows:

As shown in 222 and illustrated by Fig. 37, the shrinkage is the sum of the contraction of the inner diameter of the outer cylinder and the expansion of the outer diameter of the inner cylinder which would result from disassembling them. In other words, the relative shrinkage is given by $\phi_1 = e_t(R_1') - e_t(R_1)$, in which $e_t(R_1')$ and $e_t(R_1)$ are the circumferential strains at the two surfaces of contact which the pressure between them after assemblage (in this case $\bar{P}_1$) causes. The values of $e_t(R_1')$ and $e_t(R_1)$ we obtain from equation (13).

First taking the jacket to find $e_t(R_1')$, we substitute $\bar{P}_1$ for P_0; R_1 for R_0; R_2 for R_n; R_1 for r; and $P_n = 0$, which gives

$$e_t(R_1') = \frac{1}{E}\left[\frac{2}{3} \times \frac{\bar{P}_1 R_1^2}{(R_2^2 - R_1^2)} + \frac{4}{3} \times \frac{R_1^2 R_2^2 \bar{P}_1}{(R_2^2 - R_1^2)} \times \frac{1}{R_1^2}\right]$$

$$= \frac{1}{E}\left[\frac{2\bar{P}_1 R_1^2 + 4\bar{P}_1 R_2^2}{3(R_2^2 - R_1^2)}\right] = \frac{1}{E}\left[\frac{\bar{P}_1(2R_1^2 + 4R_2^2)}{3(R_2^2 - R_1^2)}\right].$$

Next, taking the tube to find $e_t(R_1)$, we substitute $\bar{P}_1$ for P_n; R_1 for r; and $P_0 = 0$, which gives

$$e_t(R_1) = \frac{1}{E}\left[\frac{2}{3} \times \frac{-\bar{P}_1 R_1^2}{(R_1^2 - R_0^2)} + \frac{4}{3} \times \frac{-R_0^2 R_1^2 \bar{P}_1}{(R_1^2 - R_0^2)} \times \frac{1}{R_1^2}\right]$$

$$= \frac{1}{E}\left[-\frac{2\bar{P}_1 R_1^2}{3(R_1^2 - R_0^2)} - \frac{4R_0^2 \bar{P}_1}{3(R_1^2 - R_0^2)}\right]$$

$$= -\frac{1}{E}\left[\frac{\bar{P}_1(2R_1^2 + 4R_0^2)}{3(R_1^2 - R_0^2)}\right].$$

but

$$\phi_1 = e_t(R_1') - e_t(R_1),$$

or

$$\phi_1 = \frac{1}{E}\left[\frac{\bar{P}_1(2R_1^2 + 4R_2^2)}{3(R_2^2 - R_1^2)}\right] - \left[-\frac{1}{E}\left(\frac{\bar{P}_1(2R_1^2 + 4R_0^2)}{3(R_1^2 - R_0^2)}\right)\right],$$

which, after simplifying and clearing, gives

$$\bar{P}_1 = E\,\frac{(R_1^2 - R_0^2)(R_2^2 - R_1^2)}{2R_1^2(R_2^2 - R_0^2)}\,\phi_1. \qquad (37)$$

This equation (37) gives the value of the pressure at the surface of contact caused by placing a cylinder of radii R_1 and R_2 over a cylinder of radii R_0 and R_1 with the relative shrinkage ϕ_1. The resulting circumferential strain at R_0, *i. e.*, $\bar{e}_t(R_0)$, is found from

equation (13) by substituting $\bar{P}_1$ for P_n; R_1 for R_n; R_0 for r; and $P_0=0$, which gives

$$\bar{e}_t(R_0)=\frac{1}{E}\left[\frac{2}{3}\times\frac{-\bar{P}_1R_1^2}{R_1^2-R_0^2}+\frac{4}{3}\times\frac{R_0^2R_1^2(-\bar{P}_1)}{R_1^2-R_0^2}\times\frac{1}{R_0^2}\right]$$

$$=\frac{1}{E}\left[\frac{-2\bar{P}_1R_1^2}{3(R_1^2-R_0^2)}+\frac{-4R_1^2\bar{P}_1}{3(R_1^2-R_0^2)}\right]$$

$$=-\frac{1}{E}\left[\frac{2\bar{P}_1R_1^2}{(R_1^2-R_0^2)}\right].$$

Now substituting the value of $\bar{P}_1$ from equation (37), we have

$$e_t(R_0)=-\frac{1}{E}\left[\frac{2R_1^2\left[E\frac{(R_1^2-R_0^2)(R_2^2-R_1^2)}{2R_1^2(R_2^2-R_0^2)}\phi_1\right]}{(R_1^2-R_0^2)}\right],$$

$$e_t(R_0)=-\frac{1}{E}\left[\frac{2R_1^2[E(R_1^2-R_0^2)(R_2^2-R_1^2)\phi_1]}{2R_1^2(R_2^2-R_0^2)(R_1^2-R_0^2)}\right]$$

$$\bar{e}_t(R_0)=-\frac{R_2^2-R_1^2}{R_2^2-R_0^2}\phi_1, \tag{38}$$

by which the relative compression of the bore of the inner cylinder caused by superposing the outer cylinder with the relative shrinkage ϕ_1 may be computed.

Since the only stress at the inner surface in the state of rest is the circumferential compression, the radial strain is one-third the circumferential strain given by (38).

EXAMPLES.

(1) Given $R_0=1.80''$, $R_1=2.85''$, $R_2=4.50''$, $\theta_0=\rho_0=18.75$ tons, $\theta_1=\rho_1=21.50$ tons; find $P_0(\theta)$, $P_0(\rho)$ and S_1; also the compression at R_0 in the state of rest.

$P_0(\theta)=17.11$; $P_0(\rho)=15.58$ tons.
$S_1=.0074$ in.
$\bar{P}_1=3.61$; $E\bar{e}_t(R_0)=-12.02$ tons.

(2) Given $R_0=2.85''$, $R_1=4.70''$, $R_2=7.50''$, $\theta_0=\rho_0=18.75$ tons, $\theta_1=\rho_1=21.5$ tons; find $P_0(\theta)$, $P_0(\rho)$ and S_1; also the compression at R_0 in the state of rest.

$P_0(\theta)=17.88$; $P_0(\rho)=15.91$ tons.
$S_1=.0130$ in.
$\bar{P}_1=4.03$; $E\bar{e}_t(R_0)=-12.75$ tons.

(3) Given $R_0=4.00''$, $R_1=6.35''$, $R_2=8.04''$, $\theta_0=\rho_0=18.5$ tons, $\theta_1=\rho_1=21.0$ tons; find $P_0(\theta)$, $P_0(\rho)$ and S_1; also the compression at R_0 in the state of rest.

$$P_0(\theta)=12.64;\ P_0(\rho)=13.26 \text{ tons.}$$
$$S_1=.0126 \text{ in.}$$
$$\bar{P}_1=2.01;\ E\bar{e}_t(\mathrm{R}_0)=-6.67 \text{ tons.}$$

(4) Given $R_0=6.00''$, $R_1=8.70''$, $R_2=10.46''$, $\theta_0=\rho_0=18.5$ tons, $\theta_1=\rho_1=21.0$ tons; find $P_0(\theta)$, $P_0(\rho)$ and S_1; also the compression at R_0 in the state of rest.

$$P_0(\theta)=10.25;\ P_0(\rho)=11.91 \text{ tons.}$$
$$S_1=.0148 \text{ in.}$$
$$\bar{P}_1=1.37;\ E\bar{e}_t(R_0)=-5.22 \text{ tons.}$$

(5) Given $R_0=4.00''$, $R_1=5.80''$, $R_2=7.14''$, $\theta_0=\rho_0=18.5$ tons, $\theta_1=\rho_1=21.0$ tons; find $P_0(\theta)$, $P_0(\rho)$ and S_1; also the compression at R_0 in the state of rest.

$$P_0(\theta)=10.60;\ P_0(\rho)=12.19 \text{ tons.}$$
$$S_1=.0105 \text{ in.}$$
$$\bar{P}_1=1.53;\ E\bar{e}_t(R_0)=-5.83 \text{ tons.}$$

(6) Given $R_0=4.00''$, $R_1=5.80''$, $R_2=7.14''$, if the shrinkage was $S_1=.0105$, what is the pressure at the surface of contact and what is the compression of the bore (at R_0) in the state of rest? (Compare result with answers to example (5).)

$$P_1=1.53;\ E\bar{e}_t(R_0)=-5.83 \text{ tons.}$$

Section V.—The Elastic Strength of Compound Cylinders.—Continued.

226. The true stresses, circumferential and radial, at the inner and outer surfaces of each of the elementary cylinders are readily calculated by (13) and (14), which, when applied to the case of a compound cylinder of two parts, become

Circumferential True Stresses.

$$\left.\begin{aligned}
Ee_t(R_0) &= \frac{P_0(2R_0^2+4R_1^2)-6P_1R^2}{3(R_1^2-R_0^2)} \\
Ee_t(R_1) &= \frac{6P_0R_0^2-P_1(4R_0^2+2R_1^2)}{3(R_1^2-R_0)} \\
Ee_t(R_1') &= \frac{P_1(2R_1^2+4R_2^2)}{3(R_2^2-R_1^2)} \\
Ee_t(R_2) &= \frac{2P_1R_1^2}{R_2^2-R_1^2}
\end{aligned}\right\} \quad (39)$$

Radial True Stresses.

$$(40)\quad \left\{\begin{aligned}
Ee_p(R_0) &= \frac{2P_1R_1^2+P_0(2R_0^2-4R_1^2)}{3(R_1^2-R_0^2)} \\
Ee_p(R_1) &= \frac{P_1(4R_0^2-2R_1^2)-2P_0R_0^2}{3(R_1^2-R_0^2)} \\
Ee_p(R_1') &= \frac{P_1(2R_1^2-4R_2^2)}{3(R_2^2-R_1^2)} \\
Ee_p(R_2) &= \frac{-2P_1R_1^2}{3(R_2^2-R_1^2)}
\end{aligned}\right.$$

in which, for the state of action, P_0 and P_1 have the values used in calculating the shrinkage, and, for the state of rest, P_0 is zero and P_1 is the pressure at the surface of contact when $P_0=0(\bar{P}_1)$.

Applying (39) and (40) to the example worked out in 224 for which $P_0=16.13$, $P_1=9.18$ and $P_1=5.06$, we obtain the results illustrated in Fig. 38, the right-hand side of which represents circumferential and the left-hand side radial true stresses, full lines indicating the state of action and dotted lines the state of rest.

It will be seen that in the state of action both cylinders are at the elastic limit of strain, the inner one radially and the outer one circumferentially.

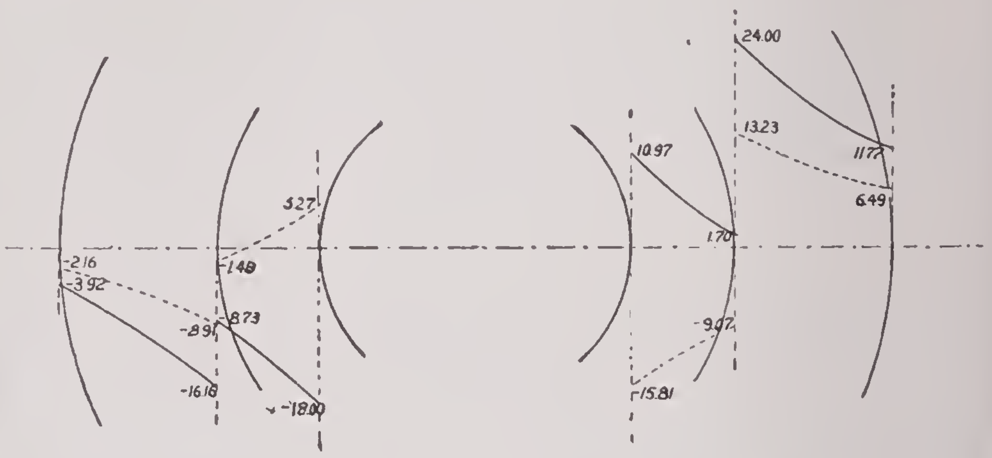


FIG. 38.

Radial True Stresses. ——————— State of action. — — — — — " " rest.

Circumferential True Stresses. ——————— State of action. — — — — — " " rest.

227. The fact that the greater the value of P_0 used in calculating the shrinkage the less the shrinkage and consequently the less the stresses in the state of rest, suggests an investigation of the results of always using $P_0(\theta)$ in (36d) instead of using $P_0(\rho)$ when it is the smaller of the two values of P_0.

In the example of 224 the shrinkage found by using $P_0(\rho)=16.13$ tons was 0.01715″; if we had used $P_0(\theta)=18.99$ tons, we would have found the shrinkage to be 0.01468″, or nearly 0.0025″ less. The true stresses in the states of action and of rest have been computed for the greater shrinkage; we will now determine their values under the same conditions ($P_0=16.13$ tons and $P_0=0$), supposing the reduced shrinkage to be used.

With the reduced shrinkage the value $P_1=9.18$ corresponds to $P_0=18.99$, and so we have first to find the change in P_1 which results from reducing P_0 from 18.99 to 16.13; this by (34) is -0.73, making the value of P_1 for our assumed state of action $9.18-0.73=8.45$. Substituting the values $P_0=16.13$ and $P_1=8.45$ in (39) and (40), we obtain the values of the true stresses in the state of action. For the state of rest we find $\overline{P}_1=4.33$ by (36c), getting the same result, of course, whether we use $P_0=18.99$ and $P_1=9.18$ or $P_0=16.13$ and $P_1=8.45$; then, putting $P_0=0$ and $P_1=\overline{P}_1=4.33$ in (39) and (40), we get the values of the true stresses in the state of rest.

The following table gives, side by side, the true stresses resulting from the use of the full and the reduced shrinkages:

				Circumferential Stress.		*Radial Stress.*	
				Full shrinkage.	Reduced shrinkage.	Full shrinkage.	Reduced shrinkage.
State of Action. $P_0=16.13$ tons.	Inner cylinder,	inner	surface	+10.97	+13.25	−18.00	−18.76
	" "	outer	"	+ 1.70	+ 3.01	− 8.73	− 8.52
	Outer "	inner	"	+24.00	+22.09	−16.16	−14.88
	" "	outer	"	+11.77	+10.83	− 3.92	− 3.61
State of Rest.	Inner "	inner	"	−15.81	−13.53	+ 5.27	+ 4.51
	" "	outer	"	− 9.07	− 7.76	− 1.48	− 1.26
	Outer "	inner	"	+13.23	+11 33	− 8.91	− 7.62
	" "	outer	"	+ 6.49	+ 5.55	− 2.16	− 1.85

228. It will be seen that the reduced shrinkage, given by adopting $P_0(\theta)$ instead of $P_0(\rho)$ as the value of P_0, results in a slight loss of elastic strength,* since the internal pressure (16.13 tons), which with full shrinkage just compressed the inner surface to its elastic limit of strain radially, with the reduced shrinkage compresses that surface slightly beyond its elastic limit. As an offset to this, the smaller shrinkage considerably reduces all the stresses in the state of rest, and those of the outer cylinder in the state of action. Moreover, there is reason to suppose that the elastic strength to resist radial compression in the case of a cylinder wall confined by an outer cylinder is greater than would be indicated by the elastic limit of compression of specimens of its material, so

* With the reduced shrinkage the internal pressure which will bring the inner surface to its elastic limit of radial strain is given by

$P_0=\frac{R_2^2-R_0^2}{R_1^2-R_0^2}\cdot\frac{3(R_1^2-R_0^2)\rho_0+2\overline{P}_1R_1^2}{4R_2^2-2R_0^2}$, the value of which for the example of 224 is 15.62 tons.

that the value of $P_0(\rho)$ may probably be exceeded without producing any permanent set. At all events, it is not radial compression, but circumferential extension, an excessive value of which will cause enlargement and ultimately rupture, and we are therefore adopting a measure of safety when we adjust the shrinkage so as to cause the elementary cylinders to reach their elastic limits of circumferential strain simultaneously, even though it be under a pressure greater than that which will cause the inner one of them to reach its elastic limit of radial strain.

For these reasons the Ordnance Departments of the United States Army and Navy have adopted the practice of disregarding the values of $P_0(\rho)$ and determining the shrinkages for the superposed cylinders of their built-up steel guns by using the values of $P_0(\theta)$.

We will follow the same method, using $P_0(\theta)$ for computing shrinkages, but still regarding $P_0(\rho)$, when it is less than $P_0(\theta)$, as the upper limit of safe internal pressure.

229. In Art. 221, by equating the simultaneous changes of circumferential strain of the two surfaces in contact at R_1, we found the relation (34) between simultaneous changes of P_0 and P_1 in the case of a compound cylinder composed of two elementary cylinders. The same relation might as readily have been found from the consideration that, within the elastic limit, the stresses and strains resulting from the application of any force are independent of prior stresses and strains, so that the effect of an internal pressure is exactly the same upon a compound cylinder as it would be upon a simple cylinder of the same dimensions. Thus, putting $P_n=0$ and substituting R_2 for R_n in (12), we obtain for the pressure at any point in a homogeneous cylinder of radii R_0 and R_2 under the sole pressure P_0

$$P(r)=\frac{P_0R_0^2}{R_2^2-R_0^2}\left(\frac{R_2^2}{r^2}-1\right), \tag{41}$$

and, making $r=R_1$ in this, we find

$$P(R_1)=\frac{R_0^2(R_2^2-R_1^2)}{R_1^2(R_2^2-R_0^2)}P_0,$$

which is the same as the relation given by (34).

230. The general principle of which the foregoing is an illustration may be stated as follows:

If any pressure be applied to a compound cylinder, the strain (or stress) at each point will be the algebraic sum of the strain (or stress) at the point before the pressure was applied and the strain (or stress) which the same pressure would cause at the corresponding point in a simple cylinder of the same dimensions as the compound one.

231. An important application of this principle shows that the maximum strength of any compound cylinder to resist internal pressure cannot exceed three-fourths the sum of the elastic limits of tension and compression of its inner elementary cylinder, regardless of the strength of its outer parts. For in the state of rest the pressure upon the inner cylinder due to the outer ones is limited to that which will compress the inner surface circumferentially to its elastic limit of compressive strain $\frac{\rho_0}{E}$; and in the state of action the internal pressure is limited to that which will extend the inner surface circumferentially to its elastic limit of tensile strain $\frac{\theta_0}{E}$; therefore the greatest allowable value of P_0 is that which, acting upon a simple cylinder of the same dimensions as the compound one, would cause the circumferential strain $\frac{\rho_0+\theta_0}{E}$ at its inner surface, and, calling the inner and outer radii R_0 and R_n, the value of this greatest pressure is by (20)

$$P_0 = \frac{3(R_n^2 - R_0^2)}{4R_n^2 + 2R_0^2}(\rho_0 + \theta_0), \tag{42}$$

the maximum value of which, when $R_n = \infty$, is $\frac{3}{4}(\rho_0+\theta_0)$, or, when $\theta_0 = \rho_0$, $\frac{3}{2}\theta$.

The maximum possible value of the elastic resistance will hereafter be denoted by $[P_0]$, and, since we accept the condition $\rho_0 = \theta_0$, it will be written

$$[P_0] = \frac{3(R_n^2 - R_0^2)}{2R_n^2 + R_0^2}\theta_0. \tag{43}$$

This is the maximum possible value of $P_0(\theta)$; $P_0(\rho)$ cannot exceed ρ_0 in value.

232. From the formulas for a compound cylinder of two parts, those for the general compound cylinder (of n parts) may be directly derived, but as the case of three elementary cylinders is

the commonest in gun construction, we will deduce the formulas for that case separately, and explain how they should be used.

We begin by finding the values of the pressures in the state of action (P_2, P_1 and P_0), supposing the cylinders to have been so assembled that they reach their elastic limits of circumferential strain simultaneously.

The outer cylinder being under the sole action of the internal pressure P_2, we have from (20)

$$P_2(\theta) = \frac{3(R_3^2 - R_2^2)}{4R_3^2 + 2R_2^2}\,\theta_2. \tag{44}$$

The middle cylinder being under the external pressure P_2 and the internal pressure P_1, of which the latter is the greater, we have from (28)

$$P_1(\theta) = \frac{3(R_2^2 - R_1^2)\theta_1 + 6P_2R_2^2}{4R_2^2 + 2R_1^2}. \tag{45}$$

And the inner cylinder being under the external pressure P_1 and the internal pressure P_0, of which the latter is the greater, we have from (28)

$$P_0(\theta) = \frac{3(R_1^2 - R_0^2)\theta_0 + 6P_1R_1^2}{4R_1^2 + 2R_0^2}. \tag{46}$$

Before adopting these values of P_2, P_1 and P_0, we must see that the shrinkages which they require will not over-compress the inner surface in the state of rest. This is most readily done by computing $[P_0]$ by (43) and comparing it with $P_0(\theta)$ from (36b); if the latter be the greater, the inner surface would be compressed beyond its elastic limit of circumferential strain when in the state of rest, and so lesser values must be assigned to one or both the elastic limits of the outer cylinders and new values of P_2, P_1 and P_0 computed. When the assumed values of θ_2, θ_1 and θ_0 are such that $[P_0]$ exceeds $P_0(\theta)$, the inner cylinder will not be too much compressed, and then the values of $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$ given by (42), (43) and (44) may be accepted.

233. The formulas for the shrinkages are deduced by the same method that was explained in Art. 222. The inner surface of the outer cylinder when in the state of action is, by hypothesis, under the circumferential strain $\frac{\theta_2}{E}$, so that its diameter is $2R_2\frac{\theta_2}{E}$ greater than when it was free (before assembling). If, then, we find the

change of diameter ($2R_2 e_t(R_2)$) of the outer surface of the middle cylinder which would result from the simultaneous removal of the outer cylinder and suppression of the internal pressure P_0, the shrinkage with which the outer cylinder was assembled will evidently be given by $S_2 = 2R_2 \frac{\theta_2}{E} + 2R_2 e_t(R_2)$.

By substituting R_2 for R_n, P_2 for P_n and R_2 for r in (13) we obtain the following expression for the circumferential strain at the outer surface of a cylinder of radii R_0 and R_2 under internal pressure P_0 and external pressure P_2:

$$e_t(R_2) = \frac{1}{E}\left[\frac{6P_0R_0^2 - P_2(4R_0^2 + 2R_2^2)}{3(R_2^2 - R_0^2)}\right]. \qquad (47)$$

But by the principle laid down in Art. 230 the same expression gives the change of strain which the application of the same pressures will cause in a compound cylinder of the same dimensions. Therefore, putting $-P_0$ and P_0 and $-P_2$ for P_2 in (47), we obtain the change of circumferential strain at R_2 due to suppressing P_0 and P_2, and this multiplied by $2R_2$ will be the change of diameter. Consequently the shrinkage of the outer cylinder is given by

$$S_2 = \frac{2R_2}{E}\left[\theta_2 + \frac{P_2(4R_0^2 + 2R_2^2) - 6P_0R_0^2}{3(R_2^2 - R_0^2)}\right]. \qquad (48)$$

Similarly the change of circumferential strain at the outer surface of the inner cylinder due to removing the two outer cylinders (*i. e.*, suppressing P_1) and simultaneously suppressing P_0 is found to be

$$e_t(R_1) = \frac{1}{E}\left[\frac{P_1(4R_0^2 + 2R_1^2) - 6P_0R_0^2}{3(R_1^2 - R_0^2)}\right] \qquad (49)$$

and so the shrinkage of the middle cylinder is

$$S_1 = \frac{2R_1}{E}\left[\theta_1 + \frac{P_1(4R_0^2 + 2R_1^2) - 6P_0R_0^2}{3(R_1^2 - R_0^2)}\right]. \qquad (50)$$

234. We have, finally, to determine the elastic strength to resist internal pressure of the system thus assembled. We know that $P_0(\theta)$ is the pressure which will bring its elementary cylinders simultaneously to their assumed elastic limits of circumferential strain, but a less pressure may bring one or more of them to the elastic limit of radial strain, and, if so, this latter pressure, and not $P_0(\theta)$, should be taken as the maximum safe pressure.

The outer cylinder being under internal pressure only, $P_2(\theta)$ is always less than $P_2(\rho)$, as explained in Art. 207. Applying (27) to the middle and inner cylinders, we obtain the following values for the respective internal pressures which will bring them to their elastic limits of radial strain:

$$P_1(\rho) = \frac{3(R_2^2 - R_1^2)\rho_1 + 2P_2R_2^2}{4R_2^2 - 2R_1^2}, \tag{51}$$

$$P_0(\rho) = \frac{3(R_1^2 - R_0^2)\rho_0 + 2P_1R_1^2}{4R_1^2 - 2R_0^2}. \tag{52}$$

If $P_1(\rho)$ given by (51) is less than the value of $P_1(\theta)$ used in computing the shrinkages, then the former is to be used for P_1 in (52) instead of the latter, and if $P_0(\rho)$ given by (52) is less than the value of $P_0(\theta)$ used in computing the shrinkages, it, and not $P_0(\theta)$, is the maximum safe pressure. That is, with $P_0(\rho) < P_0(\theta)$, the former would be a safe pressure if suitable shrinkages were assigned, but since, for good reasons, we adopt shrinkages based upon the values of $P_1(\theta)$ and $P_0(\theta)$, the actual maximum safe pressure is somewhat less than $P_0(\rho)$. We will call the true maximum safe pressure P_0, thus distinguishing it from $P_0(\rho)$ and $P_0(\theta)$; its value, when it does not equal $P_0(\theta)$, is found as follows:

The pressures in the state of rest are given by (53) and (54), the negative part of each value being the change of pressure due to the suppression of $P_0(\theta)$:

$$\overline{P}_2 = P_2(\theta) - \frac{R_0^2(R_3^2 - R_2^2)}{R_2^2(R_3^2 - R_0^2)} P_0(\theta), \tag{53}$$

$$\overline{P}_1 = P_1(\theta) - \frac{R_0^2(R_3^2 - R_1^2)}{R_1^2(R_3^2 - R_0^2)} P_0(\theta). \tag{54}$$

Then by (14) the radial strain at the inner surface of the inner cylinder, in the state of rest, is $\frac{1}{E}\frac{2\overline{P}_1R_1^2}{3(R_1^2 - R_0^2)}$, and the internal pressure which will change this radial strain to $-\frac{\rho_0}{E}$, *i. e.*, which will bring the inner surface to its elastic limit of compression radially, is, by the principle of Art. 230,

$$P_0 = \frac{3(R_3^2 - R_0^2)}{2R_0^2 - 4R_3^2}\left(-\frac{2\overline{P}_1R_1^2}{3(R_1^2 - R_0^2)} - \rho_0\right),$$

$$P_0 = \frac{R_3^2 - R_0^2}{R_1^2 - R_0^2} \cdot \frac{3(R_1^2 - R_0^2)\rho_0 + 2\overline{P}_1R_1^2}{4R_3^2 - 2R_0^2}. \tag{55}$$

The same method applied to the middle cylinder, which in the state of rest is acted on by P_2 externally and P_1 internally, would determine the internal pressure which would bring its inner surface to the elastic limit of compression radially,* but this pressure will practically always be greater than that given by (55), and, accordingly, (55) gives the true elastic strength of the system.

235. The formulas for the case of a compound cylinder composed of three elementary cylinders are grouped together in (56):

$$\left.\begin{array}{ll}
\text{(a)} & P_2(\theta)=\dfrac{3(R_3^2-R_2^2)\theta_2}{4R_3^2+2R_2^2}\,, \\[2ex]
\text{(b)} & P_1(\theta)=\dfrac{3(R_2^2-R_1^2)\theta_1+6P_2R_2^2}{4R_2^2+2R_1^2}\,, \\[2ex]
\text{(c)} & P_0(\theta)=\dfrac{3(R_1^2-R_0^2)\theta_0+6P_1R_1^2}{4R_1^2+2R_0^2}\,, \\[2ex]
\text{(d)} & P_0(\theta)<\dfrac{3(R_3^2-R_0^2)(\theta_0+\rho_0)}{4R_3^2+2R_0^2}\,, \\[2ex]
\text{(e)} & P_1(\rho)=\dfrac{3(R_2^2-R_1^2)\rho_1+2P_2R_2^2}{4R_2^2-2R_1^2}\,, \\[2ex]
\text{(f)} & P_0(\rho)=\dfrac{3(R_1^2-R_0^2)\rho_0+2P_1R_1^2}{4R_1^2-2R_0^2}\,, \\[2ex]
\text{(g)} & S_2=\dfrac{2R_2}{E}\left[\theta_2+\dfrac{P_2(\theta)(4R_0^2+2R_2^2)-6P_0(\theta)R_0^2}{3(R_2^2-R_0^2)}\right], \\[2ex]
\text{(h)} & S_1=\dfrac{2R_1}{E}\left[\theta_1+\dfrac{P_1(\theta)(4R_0^2+2R_1^2)-6P_0(\theta)R_0^2}{3(R_1^2-R_0^2)}\right], \\[2ex]
\text{(i)} & \bar{P}_2=P_2(\theta)-\dfrac{R_0^2(R_3^2-R_2^2)}{R_2^2(R_3^2-R_0^2)}\,P_0(\theta), \\[2ex]
\text{(j)} & \bar{P}_1=P_1(\theta)-\dfrac{R_0^2(R_3^2-R_1^2)}{R_1^2(R_3^2-R_0^2)}\,P_0(\theta), \\[2ex]
\text{(k)} & P_0=\dfrac{R_3^2-R_0^2}{R_1^2-R_0^2}\cdot\dfrac{3(R_1^2-R_0^2)\rho_0+2\bar{P}_1R_1^2}{4R_3^2-2R_0^2}\,.
\end{array}\right\}\quad(56)$$

The method of procedure is as follows:

(1) Calculate $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$ by (a), (b) and (c), using for θ_2, θ_1 and θ_0 the elastic limits of the materials as determined in a testing machine.

* The formula is .

$$P_0=\frac{R_1^2(R_3^2-R_0^2)}{R_0^2(4R_3^2-2R_1^2)(R_2^2-R_1^2)}\,[3(R_2^2-R_1^2)\rho_1+2\bar{P}_2R_2^2-\bar{P}_1(4R_2^2-2R_1^2)].$$

(2) See if the condition (d) is fulfilled. If it is not, find new values of $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$, using values of θ_2 and θ_1 (one or both) sufficiently less than their true values to cause the condition (d) to be met.

(3) Calculate the shrinkages by (g) and (h), using the values of θ_2, θ_1, $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$ which satisfied (d).

(4) Calculate $P_1(\rho)$ and $P_0(\rho)$ by (e) and (f), using for ρ_0 and ρ_1 the true elastic limits of the materials, and for P_1 in (f) putting whichever is least, $P_1(\rho)$ or the value of $P_1(\theta)$ calculated with the true values of θ_2 and θ_1.

(5) If $P_0(\rho)$ is greater than the value of $P_0(\theta)$ used in computing the shrinkages, the latter is the true measure of the elastic strength of the system; if it be less, then P_0, calculated by (k), is the true measure.

236. To find the state of strain at the inner surface (at R_0) caused by superposing the two outer cylinders with relative shrinkages, respectively ϕ_1 and ϕ_2, we have only to apply (38) to this case, the strain resulting from the compressive action of both outer cylinders being merely the sum of the strains caused by their actions considered separately. Thus we have

$$\bar{e}_t(R_0) = -\frac{R_2^2 - R_1^2}{R_2^2 - R_0^2}\,\phi_1 - \frac{R_3^2 - R_2^2}{R_3^2 - R_0^2}\,\phi_2. \qquad (57)$$

Moreover, the radial strain at the inner surface in the state of rest ($\bar{e}_p(R_0)$) will be one-third the circumferential strain given by (57).

EXAMPLES.

(1) Given $R_0 = 7.0''$, $R_1 = 9.5''$, $R_2 = 15.0''$, $R_3 = 21.0''$; if $\theta_0 = \rho_0 = 20.0$ tons, what is the greatest possible value of the internal pressure which can be withstood elastically? If $\theta_0 = 20.0$, $\theta_1 = 21.4$ and $\theta_2 = 22.3$ tons, find $P_0(\theta)$, S_1 and S_2. What is the true elastic strength after assemblage with the shrinkages based on the value of $P_0(\theta)$?

$[P_0] = 25.26$; $P_0(\theta) = 24.46$ tons.
$S_1 = .0183$; $S_2 = .0386$.
$\bar{P}_1 = 4.28$; $P_0 = 18.52$ tons.

(2) Given $R_0 = 5.0''$, $R_1 = 9.5''$, $R_2 = 15.0''$, $R_3 = 19.0''$, $\theta_0 = \rho_0 = 20.0$ tons; what is the limiting value for the internal pressure?

If $\theta_0=20.0$, $\theta_1=21.0$, and $\theta_2=24$ tons, find $P_0(\theta)$. If assembled with the shrinkages corresponding to the value of $P_0(\theta)$, what would be the compression at R_0 in the state of rest?

$[P_0]=26.99$; $P_0(\theta)=28.39$ tons.
22.06 tons.

(3) Given $R_0=6.0''$, $R_1=10.3''$, $R_2=15.0''$, $R_3=17.7''$, $\theta_0=17.5$ tons, $\theta_1=22.0$ tons, $\theta_2=22.0$ tons; find $[P_0]$, $P_0(\theta)$, S_1 and S_2.

$[P_0]=21.97$; $P_0(\theta)=21.79$ tons.
$S_1=.0296$; $S_2=.0400$ in.

(4) Given $R_0=4.75''$, $R_1=7.50''$, $R_2=11.375''$, $R_3=14.375''$, $\theta_0=16$ tons, $\theta_1=17$ tons, $\theta_2=22.2$ tons; find $P_0(\theta)$, S_1 and S_2.

$P_0(\theta)=20.68$ tons; $S_1=.0149$; $S_2=.0327$ in.

(5) Given $R_0=6.0''$, $R_1=11.0''$, $R_2=17.0''$, $R_3=21.0''$, $\theta_0=18.0$, $\theta_1=19.0$, $\theta_2=21$ tons; find $[P_0]$, $P_0(\theta)$, S_1, S_2 and P_0.

$[P_0]=23.82$; $P_0(\theta)=23.82$ tons.
$S_1=.0287$; $S_2=.0476$ in.
$\bar{P}_1=6.32$; $P_0=17.23$ tons.

(6) Given $R_0=6.0''$, $R_1=11.0''$, $R_2=17.0''$ and $R_3=21.0''$, if the shrinkages were $S_1=.0287$ and $S_2=.0476$, find the circumferential and radial true stresses at the inner surface (at R_0) in the state of rest. Then, by the principle of Art. 230, find the internal pressures which will strain the inner surface to the elastic limit (18 tons) first radially and second circumferentially. (Compare results with answers to example (5).)

$E\bar{c}_t(R_0)=18.09$; $E\bar{c}_p(R_0)=6.03$ tons.
$P_0(\theta)=23.87$; $P_0(\rho)=17.25$ tons.

Section VI.—Applications to Built-Up Guns.

237. The modern gun is essentially a compound cylinder, but, being constructed to withstand an internal pressure which diminishes from the breech end to the muzzle, the number of layers and the exterior dimensions are correspondingly decreased for economy of weight, making it necessary to divide the whole length into a number of sections for each of which a separate computation of the elastic strength and shrinkages must be made. In United States guns the inner layer, in which are formed the

chamber and bore proper, is called the *tube;* the second layer consists of a *jacket,* in which the breech block is housed, and *chase hoops,* which extend from the front end of the jacket nearly or quite to the muzzle; over that part of the bore in which the maximum powder pressure acts a third and sometimes a fourth layer of *hoops* is placed. With increase of knowledge and of facilities larger and larger steel forgings of assured good quality have become available, and the number of separate parts constituting a built-up gun has tended to diminish, so that at the present time the outer layers, as well as the tube, are sometimes made in one piece.

In one particular, however, there is an important difference between a gun and the compound cylinders with free ends which we have thus far considered; in the latter there is no longitudinal stress, while in a gun the internal pressure, acting upon the breech block as well as upon the cylinder walls, gives gise to a longitudinal stress of very considerable intensity.

238. The longitudinal stress.—If we consider a gun recoiling freely under the action of the powder pressure on the bottom of its bore, we see that the total longitudinal stress on any cross-section of the gun must equal the product of the acceleration by the mass forward of the section,* so that the said stress diminishes rapidly as we go forward from the front thread of the screw box, where it is a maximum. When recoil is resisted by a brake of any kind, the acceleration is reduced and so, to the same extent, is the longitudinal stress on all cross-sections forward of the point of attachment of the brake to the gun; in rear of that point the longitudinal stress is increased by the action of the recoil brake, the increase diminishing as the cross-section through the front thread of the screw box is approached till, at that point, the total longitudinal stress is practically the same as in free recoil. When, as in most modern United States naval gun mounts, the pistons of the recoil cylinders are attached to a yoke around the breech of the gun, the longitudinal stress is diminished at all sections, its maximum value then being $\frac{M'}{M}(\pi R_0^2 P - F)$, in which M is the whole recoiling mass, M' is that part of it which is forward of the front thread of the screw box, R_0 is the radius of bore and P the maximum powder

* $F = M\alpha$ where $F =$ force; $M =$ mass, and $\alpha =$ acceleration.

pressure, and F is the total resistance * of the recoil brake at the instant when P acts.

We do not know how the total longitudinal stress is distributed over the cross-section of the gun. It is not wholly borne by the layer in which the breech block houses (the jacket in United States guns), for there is an enormous frictional resistance to the longitudinal motion of any one layer relative to the others; if it were uniformly distributed over the jacket alone, its intensity, even at the section of greatest stress, would seldom exceed 5 or 6 tons per square inch, and if, as many writers assume, it is uniformly distributed over the whole cross-section of the gun, its greatest intensity will not exceed 2 or 3 tons per square inch. Probably the latter assumption is practically true at some distance forward of the breech block and is not very far from the truth at any point forward of the gas check.

Moreover, this maximum intensity of longitudinal stress only exists for the infinitesimally small period of time during which the maximum powder pressure is maintained; during the greater part of the time in which the gun is subjected to internal pressure the longitudinal stress is very small, even at the section where it has its greatest value.

For these reasons, therefore, we are justified in applying to guns the formulas which we have deduced for cylinders with free ends.

239. If circumferential strain alone had to be considered in the case of a compound cylinder, the greatest strength would be obtained by making the successive radii of the elementary cylinders increase in geometrical progression, provided their physical characteristics were the same. Thus, for the case of any one cylinder superimposed upon another, we first substitute the value of P_1 from equation (36a) in equation (36b). Then regarding $P_0(\theta)$ in (36b) as a function of R_1 (R_0 and R_2 constant, and $\theta_1 = \theta_0$), and, since we are seeking the maximum value, putting $\dfrac{dP_0(\theta)}{dR_1} = 0$, we find, after simplification, $R_1^2 = R_0 R_2$, which shows that the maximum value of $P_0(\theta)$ for a given total thickness of a given material occurs when the radius of the common surface is a mean

* This total resistance of the recoil brake, however, is never more than a small fraction of the maximum total pressure on the bottom of the bore of the gun.

proportional between the inner and outer radii. Very nearly the same proportions will also give the greatest strength as regards radial strain.

In practive, however, other considerations govern in the proportioning of the layers of which guns are composed. In the first place the layer in which the breech block is housed, even though other layers assist it in taking the longitudinal stress, should be of sufficient cross-section to itself safely sustain that stress. Again, the thickness of the tube over the chamber should be sufficient to make relining practicable in case erosion wears away the rifling, and its thickness elsewhere should be sufficient to give ample stiffness. Finally, the necessity for keeping down the weight, which prescribes a decreasing exterior diameter towards the muzzle, and the need for avoiding sudden or great changes of the sections of the different layers, often require dimensions not otherwise desirable.

240. In assigning shrinkages for the different parts of a gun, while as a general rule the maximum attainable strength should be sought at each section, great changes of shrinkage in passing from one section to another must be avoided, as they would cause undesirable inequalities of strain. Not only should each of the parts which make up the outer layers of the gun be assembled so that the strains at its inner surface, both in the state of rest and in that of action, do not change abruptly at any point of its length, but the tube, similarly throughout its length, should be under a compression in the state of rest, and of extension in the state of action, which only gradually varies and at no point changes abruptly. Furthermore, as a rule, slack shrinkages should be preferred to excessive ones, to the end that under the action of an excessive pressure it may be the tube which gives way rather than an outer part.

241. As a simple example of the method of determining the proper shrinkages, and the elastic strength of a gun, we will consider the case of the United States naval 5-inch B. L. R. Mark V, which is shown in Plate I, with its curves of computed elastic strength and of strains at rest and in action.

The computations are made separately for each of the sections indicated on the drawing, but only those for the most important section, that through the chamber, will be worked out in the text, the final results of the other computations, which are obtained in

exactly the same way, being merely stated. As it is always necessary to adjust the shrinkages, in accordance with the principle set forth in Art. 240, it is most convenient to find their values, as well as the values of the pressures in the state of action, in terms of the elastic limits of the different layers, afterwards assigning suitable values to the elastic limits, always, of course, within their true values as indicated by the testing machine.

5-Inch B. L. R. Mark V.

Section I.

$R_0 = 3.50$	$R_0^2 = 12.25$	$3(R_3^2 - R_0^2) = 278.43$ ....log	2.44472
$R_1 = 5.25$	$R_1^2 = 27.56$	$2R_3^2 + R_0^2 = 222.37$ .... "	2.34707
$R_2 = 8.25$	$R_2^2 = 68.06$	"	0.09765
$R_3 = 10.25$	$R_3^2 = 105.06$	$\theta_0 = 20.0$ .... "	1.30103
		$P_0 = 25.4$ .... "	1.39868 (43)

$\theta_0 = p_0 = 20.0$ tons
$\theta_1 = p_1 = 21.5$ "
$\theta_2 = p_2 = 22.0$ " *

That is, 25.04 tons is the greatest possible elastic strength, whatever the qualities of the jacket and hoop.

$3(R_3^2 - R_2^2) = 112.00$........log	2.04532
$4R_3^2 + 2R_2^2 = 556.36$........ "	2.74536
A_2................ "	9.29996 (56a)
$\theta_2 = 22.0$ .... "	1.34242
$P_2(\theta) = 4.389$....... "	.64238

$$P_2(\theta) = A_2\theta_2 = [9.29996]\theta_2$$

$3(R_2^2 - R_1^2) = 121.50$......log	2.08458	$6R_2^2 = 408.36$........log	2.61104
$4R_2^2 + 2R_1^2 = 327.36$...... "	2.51503	.... "	2.51503
A_1............... "	9.56955	B_1.................. "	.09601
$\theta_1 = 21.5$....... "	1.33244	A_2.................. "	9.29996 (56b)
7.980..... "	.90199	B_1A_2.................. "	9.39597
		$\theta_2 = 22.0$.......... "	1.34242
5.475..................................		"	.73839

$P_1(\theta) = 13.455$

$$P_1(\theta) = A_1\theta_1 + B_1A_2\theta_2 = [9.56955]\theta_1 + [9.39597]\theta_2$$

$3(R_1^2 - R_0^2) = 45.93$..log	1.66210	$6R_1^2 = 165.36$..log	2.21843	B_1A_2..log	9.39597
$4R_1^2 + 2R_0^2 = 134.74$.. "	2.12950	.... "	2.12950		
A_0........... "	9.53260	B_0............ "	.08893	.... "	.08893
$\theta_0 = 20.0$... "	1.30103	A_1............ "	9.56955		
6.818 "	.83363	B_0A_1............ "	9.65848	$B_0B_1A_2$.. "	9.48490
		$\theta_1 = 21.5$..... "	1.33244		(56c)
9.793............................		"	.99092	$\theta_2 = 22.0$ "	1.34242
6.719..				"	.82732

$P_0(\theta) = 23.330$

$$P_0(\theta) = A_0\theta_0 + B_0A_1\theta_1 + B_0B_1A_2\theta_2 = [9.53260]\theta_0 + [9.65848]\theta_1 + [9.48490]\theta_2$$

* These are the true elastic limits, being the least values given by any of the specimens taken respectively from the tube, jacket and hoop.

The value of $P_0(\theta)$ for the true values of the elastic limits being 23.33 tons, while $[P_0]=25.04$ tons, the inner surface is not too much compressed in the state of rest, and so we proceed to determine the shrinkages.

$6R_0^2 =$ 73.50 .... log 1.86629
$2R_1 =$ 10.50 .... log 1.02119
$E =$ 13000.0 .... " 4.11394

$\frac{2R_1}{E} =$ .0008077 .... " 6.90725 .... " 6.90725
$4R_0^2+2R_1^2 =$ 104.12 .... " 2.01753

" 8.92478 " 8.77354
$3(R_1^2-R_0^2) =$ 45.93 .... " 1.66210 .... " 1.66210

" 7.26268 .... log 7.26268 " 7.11144 ... log 7.11144 ... log 7.11144
A_1 .... " 9.56955 A_0 " 9.53260 (56f)
B_1A_2 .... " 9.39597 B_0A_1 .... " 9.65848

" 6.83223 .... " 6.65865 $B_0B_1A_2$ .... " 9.48490

log 6.64404 " 6.76992 " 6.59634

$+.0008077\,\theta_1 + .0006796\,\theta_1 + .0004557\,\theta_2 - .0004406\,\theta_0 - .0005887\,\theta_1 - .0003948\,\theta_2$
+.0006796 − .0003948

+.0014873 + .0000609
−.0005887

+.0008986

$S_1 = .0008986\,\theta_1 - .0004406\,\theta_0 + .0000609\,\theta_2$

$6R_0^2 =$ 73.50 .... log 1.86629
$2R_2 =$ 16.50 ..... log 1.21748
$E =$ 13000.00 ...., " 4.11394

$\frac{2R_2}{E} =$ .0012692 ..... " 7.10354 ..... " 7.10354
$4R_0^2+2R_2^2 =$ 185.12 ..... " 2.26745

" 9.37099 " 8.96983
$3(R_2^2-R_0^2) =$ 167.43 ..... " 2.22383 ..... " 2.22383

" 7.14716 ..... " 6.74600 ..... log 6.74600 ..... log 6.74600
A_2 .... " 9.29996 A_0 " 9.53260 (56g)
" 6.44712 B_0A_1 .... " 9.65848
$B_0B_1A_2$ .... " 9.48490

" 6.27860 " 6.40448 " 6.23090

$+.0012692\theta_2 + .0002800\theta_2 - .0001899\theta_0 - .0002538\theta_1 - .0001702\theta_2$
+.0002800

+.0015492
−.0001702

+.0013790

$S_2 = .0013790\theta_2 - .0001899\theta_0 - .0002538\theta_1$

Now, substituting the values 20.0, 21.5 and 22.0 for θ_0, θ_1 and θ_2, respectively, we have for the shrinkages which will cause tube, jacket and hoop to simultaneously reach their elastic limits of circumferential strain, under the internal pressure $P_0(\theta)=23.33$ tons, $S_1=.01185$ and $S_2=.02108$.

In exactly the same way as shown for Section I, the values of the pressures in the state of action and the corresponding shrinkages are computed for the other sections, the results being as follows:

Section II.

$$\left.\begin{array}{l} R_0 = 2.70 \\ R_1 = 5.25 \\ R_2 = 8.25 \\ R_3 = 10.25 \end{array}\right\} \begin{array}{l} P_2(\theta) = [9.29996]\theta_2 \\ P_1(\theta) = [9.56955]\theta_1 + [9.39597]\theta_2 \\ P_0(\theta) = [9.69769]\theta_0 + [9.69170]\theta_1 + [9.51812]\theta_2 \\ \quad S_1 = .0010376\theta_1 - .0002896\theta_0 + .0000983\theta_2 \\ \quad S_2 = .0013976\theta_2 - .0001508\theta_0 - .0001488\theta_1 \end{array}$$

Section III.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 5.25 \\ R_2 = 8.25 \\ R_3 = 9.00 \end{array}\right\} \begin{array}{l} P_2(\theta) = [8.92618]\theta_2 \\ P_1(\theta) = [9.56955]\theta_1 + [9.02219]\theta_2 \\ P_0(\theta) = [9.71671]\theta_0 + [9.69899]\theta_1 + [9.15163]\theta_2 \\ \quad S_1 = .0009470\theta_1 - .0002468\theta_0 + .0000559\theta_2 \\ \quad S_2 = .0012509\theta_2 - .0001919\theta_0 - .0001842\theta \end{array}$$

Section IV.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 5.25 \\ R_2 = 8.00 \end{array}\right\} \begin{array}{l} P_1(\theta) = [9.54577]\theta_1 \\ P_0(\theta) = [9.71671]\theta_0 + [9.67521]\theta_1 \\ \quad S_1 = .0009391\theta_1 - .0002468\theta_0 \end{array}$$

Section V.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 5.00 \\ R_2 = 7.00 \end{array}\right\} \begin{array}{l} P_1(\theta) = [9.46639]\theta_1 \\ P_0(\theta) = [9.69897]\theta_0 + [9.59133]\theta_1 \\ \quad S_1 = .0008693\theta_1 - .0002564\theta_0 \end{array}$$

Section VI.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 5.00 \\ R_2 = 5.50 \end{array}\right\} \begin{array}{l} P_1(\theta) = [8.96428]\theta_1 \\ P_0(\theta) = [9.69897]\theta_0 + [9.08922]\theta_1 \\ \quad S_1 = .0008007\theta_1 - .0002564\theta_0 \end{array}$$

Section VII.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 5.00 \end{array}\right\} P_0(\theta) = [9.69897]\theta_0$$

Section VIII.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 3.8735 \end{array}\right\} P_0(\theta) = [9.55930]\theta_0$$

Section IX.

$$\left.\begin{array}{l} R_0 = 2.50 \\ R_1 = 4.50 \end{array}\right\} P_0(\theta) = [9.65244]\theta_0$$

242. We adopt as the shrinkages for that part of the gun which is represented by Section I the values $S_1 = .0120$ and $S_2 = .0210$, being (to the nearest thousandth of an inch) those which result from substituting the true values θ_0, θ_1 and θ_2 in the expressions for S_1 and S_2.

If now we compute the shrinkages for Section II with the same values of θ_0, θ_1 and θ_2, we find $S_1 = .0165$, $S_2 = .0197$ and $P_0(\theta) = 27.79$ tons, and as the increase of strength over the adjoining section would be valueless, while the great increase of the jacket shrinkage would cause a very undesirable inequality of strains in the state of rest, we see that it will be best to assign less values to θ_1 and θ_2 and to adopt a correspondingly less shrinkage for this section. If, on the other hand, we should adopt the same shrinkages for Section II as for Section I, an internal pressure which would bring the bore to its elastic limit would only cause a circumferential true stress of about 16.6 tons at the inner surface of the jacket, thus causing an undesirable inequality of strains in the state of action, since in the adjoining section the jacket reaches its elastic limit with the tube. We therefore compromise between the two extremes, and adopt the values $S_1 = .0130$ and $S_2 = .0200$ for part of the gun which Section II represents.

Guided by similar considerations, we assign to the shrinkages at the other sections the values stated on the drawing.

We might now, by means of the general values of S_1 and S_2 which we have computed for each section, find the values of θ_1 and θ_2 which, in combination with the value 20.0 for θ_0, will give the shrinkages which have been adopted, and then, with those values of θ_0, θ_1 and θ_2, calculate the elastic strength, compression of bore in the state of rest, etc. A better method, however, is to start afresh and with the given shrinkages calculate first, by (57), the circumferential and radial strains at the surface of the bore in the state of rest and then the internal pressure which will increase each of those strains to its greatest allowable value. We will do this for Section II, as an illustration.

$$\left.\begin{array}{ll} R_0 = 2.70 & R_0^2 = 7.29 \\ R_1 = 5.25 & R_1^2 = 27.56 \\ R_2 = 8.25 & R_2^2 = 68.06 \\ R_3 = 10.25 & R_3^2 = 105.06 \end{array}\right\} \begin{array}{l} S_1 = .0130;\ \phi_1 = \dfrac{S_1}{2R_1} = .0012381 \\[2ex] S_2 = .0200;\ \phi_2 = \dfrac{S_2}{2R_2} = .0012121 \end{array}$$

$R_2^2 - R_1^2 =$	40.5	. . log 1.60746	$R_3^2 - R_2^2 =$	37.0	. . log 1.56820
$\phi_1 =$	.0012381 . .	" 7.09275	$\phi_2 =$	.0012121 . .	" 7.08354
		" 8.70021			" 8.65174
$R_2^2 - R_0^2 =$	60.77	. . " 1.78369	$R_3^2 - R_0^2 =$	97.77	. . " 1.99021
	.0008251 . .	" 6.91652			
	.0004587			. . . .	" 6.66153
$\bar{c}_t(R_0) =$	$-$ .0012838 . .	" 7.10850			
$E =$	13000	. . " 4.11394			
$E\bar{c}_t(R_0) =$	$-$ 16.69	. . " 1.22244			
$E\bar{c}_p(R_0) =$	$+$ 5.56				

The true circumferential stress at the surface of the bore in the state of rest is thus found to be -16.69 tons, while the true radial stress is $+5.56$ tons. Therefore, applying the principle laid down in Art. 230, the internal pressures which will, respectively, bring the inner surface to its elastic limits of strain circumferentially and radially are found as follows:

$3(R_3^2 - R_0^2) =$	293.31	log 2.46733	log 2.46733
$\theta_0 + 16.69 =$	36.69	" 1.56455	
$\rho_0 + 5.56 =$	25.56		" 1.40756
		" 4.03188	" 3.87489
$4R_3^2 + 2R_0^2 =$	434.82	" 2.63831	
$4R_3^2 - 2R_0^2 =$	405.66		" 2.60816
$P_0(\theta) =$	24.75	" 1.39357	
$P_0(\rho) =$	18.48		" 1.26673

In the same way at each of the other sections the effect upon the bore of superposing the outer cylinders with the adopted shrinkages is first calculated, and thence the elastic strength of the assembled system is determined, the results being as shown by the curves in Plate I.

243. Since the compression of the bore caused by superposing the hoop with the relative shrinkage ϕ_2 is by (38) $\dfrac{R_3^2 - R_2^2}{R_3^2 - R_0^2} E\phi_2$, the pressure at the surface of contact in the state of rest must be

$$\bar{P}_2 = \frac{R_2^2 - R_0^2}{2R_2^2} \frac{R_3^2 - R_2^2}{R_3^2 - R_0^2} E\phi_2, \tag{58}$$

and, since the whole compression of the bore in the state of rest is by (57) $\dfrac{R_2^2 - R_1^2}{R_2^2 - R_0^2} E\phi_1 + \dfrac{R_3^2 - R_2^2}{R_3^2 - R_0^2} E\phi_2$, we have similarly

$$\bar{P}_1 = \frac{R_1^2 - R_0^2}{2R_1^2} \left(\frac{R_2^2 - R_1^2}{R_2^2 - R_0^2} E\phi_1 + \frac{R_3^2 - R_2^2}{R_3^2 - R_0^2} E\phi_2 \right). \tag{59}$$

Thus we obtain the values of the pressures in the state of rest at each of the sections of the gun, and from them, together with the known value of P_0, the strains in the state of rest and of action may be found.

The following table gives the results of the calculations for the 5-inch gun shown in Plate I:

SECTIONS.

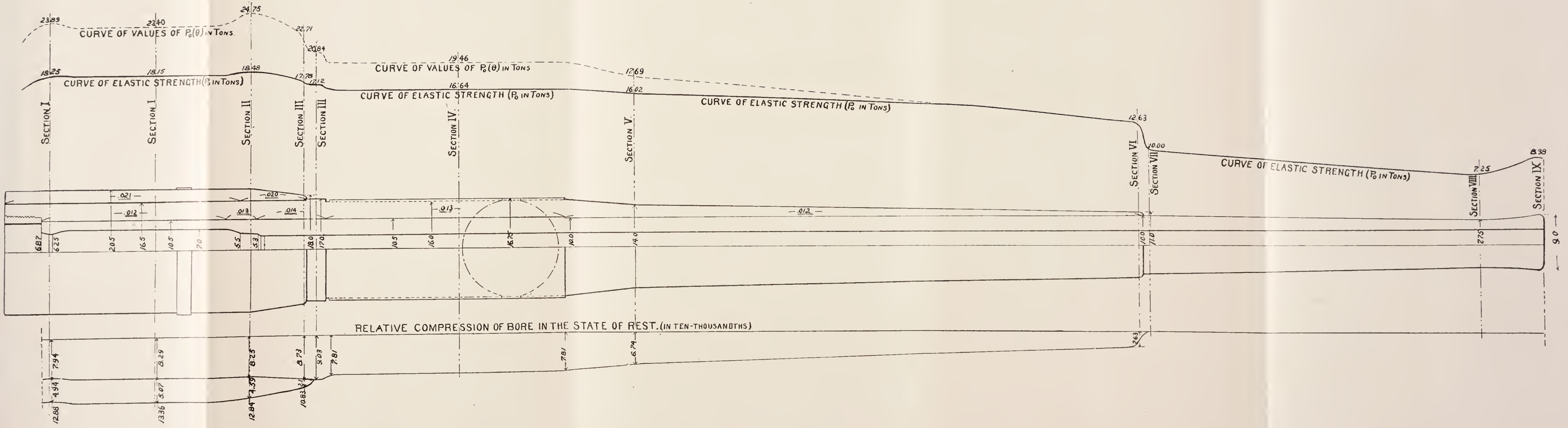
	I'	*I*	*II*	*III*	*III'*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*
$P_0(\theta)$	23.89	23.40	24.75	22.71	20.84	19.46	17.69	12 63	10.00	7.25	8.98
P_0	18.25	18.15	18.48	17.78	17.12	16.64	16.02	12.63	10.00	7.25	8 98
$\bar{P}_2$	2.75	2.70	2.66	1.24	.....	.....	.....	.....	.....	.....	.....
$\bar{P}_1$	5.41	4.83	6.14	5.45	4.54	3.93	3.29	1.28	.....	.....	.....
$E\bar{e}_t(R_0)$	−16.75	−17.38	−16.69	−14.09	−11.74	−10.16	− 8.76	− 3.41	.....	.....	.....
$E\bar{e}_t(R'_1)$	+ 5.32	+ 3.92	+ 7.59	+10.52	+11.65	+11.18	+11.22	+13.88	.....	....	.....
$E\bar{e}_t(R'_2)$	+13.79	+13.56	+13.34	+14.68	.....	.....	.....	.....	.....	.....	.....
$Ee_t(R_0)$	+11.32	+11.61	+10.71	+12.60	+14.21	+15.63	+17.28	+20.00	+20.00	+20.00	+20.00
$Ee_t(R'_1)$	+16.07	+17.69	+15.51	+17.34	+18.40	+17.96	+18.90	+21.38	.....	.....	.....
$Ee_t(R'_2)$	+18.88	+20.09	+17.10	+18.03	.....	.....	.....	.....	.....	.....	.....

244. The method of procedure when there are more than three layers is exactly the same as has been explained for the cases of two and three layers respectively, and the formulas already deduced are easily extended to cover any number of layers whatever. For the convenience of any one who may wish to use them, the formulas for the case of four layers are given in full in an appendix.

Section VII.—Elementary Gun Design.*

245. **General Considerations.**—The modern high-powered gun is essentially a compound cylinder designed to withstand rapidly varying but not instantaneous internal pressures. The object of the subdivision of the gun into various elements is twofold: 1st, to increase the range through which the metal of the gun may be worked and thus increase the magnitude of the resisting elastic forces by assembling the elements with shrinkage; and 2d, to insure the homogeneity of the metal and thus the safety of the gun by its subdivision into sufficiently small elements. It is a principle of metallurgy, in the present state of the art, that there is a practical limit to the size of cast-steel ingots. If this size, which may

* Written by Lieutenant (j. g.) R. K. Turner, U. S. Navy, at the Naval Gun Factory, February, 1916.


CURVE OF VALUES OF $P_0(\theta)$ IN TONS.
CURVE OF ELASTIC STRENGTH (P_0 IN TONS)
CURVE OF VALUES OF $P_0(\theta)$ IN TONS
CURVE OF ELASTIC STRENGTH (P_0 IN TONS)
CURVE OF ELASTIC STRENGTH (P_0 IN TONS)
CURVE OF ELASTIC STRENGTH (P_0 IN TONS)
SECTION I
SECTION I
SECTION II
SECTION III
SECTION III
SECTION IV
SECTION V
SECTION VI
SECTION VII
SECTION VIII
SECTION IX
RELATIVE COMPRESSION OF BORE IN THE STATE OF REST. (IN TEN-THOUSANDTHS)

be determined solely by experience for each kind of steel, is exceeded, the ingot will have unsound areas which no subsequent forging can entirely cure. This unsound metal, in the forms commonly known as segregations, sand splits, streaks, and blow holes, must be carefully avoided during manufacture if the guns are to merit a proper degree of confidence. Manufacturing processes are undergoing constant improvement, but at the present time two principles must be invariably considered in gun construction: 1st, that in high-powered guns there should be at least two elements resisting stresses whose character is definitely known; and 2d, that a sound forging cannot be obtained if its wall thickness, its length, and its diameter are all very great. Furthermore, the weight of a gun has an important bearing on its mounting on board ship, and since the weight increases nearly proportionally to the cube of the caliber it is apparent that this fact and the above two considerations tend to limit the caliber and power of naval guns.

If a pressure curve is drawn from the formulas of interior ballistics, it is seen that the whole gun in rear of the base of the projectile is subjected to the pressure represented by the successive ordinates passed by the projectile during its travel down the bore. When the base is opposite the maximum ordinate the whole gun in rear of this ordinate is subjected to the maximum pressure and should therefore be cylindrical from the breech to this point. The forward portion of the gun, however, is subjected to continuously decreasing pressures and may therefore continuously decrease in thickness. This decrease in thickness may be theoretically proportional to the decrease in height of the pressure ordinates. For this reason the gun is made smaller at the muzzle than at the breech and thus an economy in weight and cast is effected. The muzzle itself is flared out in the form of a bell because the metal at that point is not supported on the forward side and it is thought that the absence of slightly extra strength might induce splitting. We know that the resistance formulas do not tell the whole truth, since they take into consideration neither the supporting nor the shearing effect due to the continuation of the metal beyond the particular section considered, but experience has shown that the formulas in use give the best approximate mathematical measure of the strength of the gun as a whole, at least relatively to guns of proved worth.

246. Longitudinal resistance.—In the deduction of the resistance formulas the gun is considered to be undergoing strains in the planes normal to the axis only. This assumption does not accord with the facts, since part of the gun resists for a short time the total gas pressure on the face of the breech block. Suppose that section of the gun which takes this pressure, *i. e.*, those elements to which the block transmits its stresses, have inner and outer radii of R_0' and R_n', respectively, and the minimum obturator radius is ρ_0, the bore pressure per square inch being P_0. If the gun did not recoil, the section under consideration would sustain a longitudinal stress T in addition to the transverse stresses, such that

$$\pi\rho_0{}^2P_0=\pi(R_n'^2-R_0'^2)\times T$$

and

$$T=\frac{\rho_0{}^2P_0}{R_n'^2-R_0'^2}. \qquad (75)$$

This stress would exist only to the rear of the plane of attachment of the gun to the carriage, which is usually a shoulder turned on the outside near the breech. A yoke to which the piston rods are secured takes against this shoulder.

As a matter of fact, however, the gun recoils, and in doing so relieves this stress to a certain extent. Let W be the weight of the recoiling parts, w_1 the weight to the rear of the longitudinal instantaneous center of pressure of the screw-box liner, v the velocity of recoil, and R_c the constant brake resistance; the total effective thrust, F, on the breech of the gun, neglecting the friction of the projectile in the bore, will be

$$F=ma=\frac{W}{g}\frac{dv}{dt}.$$

The total rearward force across any section forward of the breech diminishes proportionally to the decrease of the mass forward of that section. Therefore the maximum stress will be in the plane of the longitudinal instantaneous center of pressure between the screw-box liner and the gun. The force F' at this point will be:

$$F'=m'a=\frac{W-w_1}{g}\frac{dv}{dt}$$

and the ratio between the two forces is

$$\frac{F'}{F}=\frac{W-w_1}{W}, \text{ or } F'=F\times\frac{W-w'}{W}.$$

But the total force acting to push the gun to the rear is the difference between the total gas pressure and the constant brake resistance, or

$$F=\pi\rho_0{}^2P_0-R_e,$$

and therefore the total stress on the metal of the gun is

$$F'=\frac{W-w'_1}{W}(\pi\rho_0{}^2P_0-R_e)$$

and the unit longitudinal stress is

$$T=\frac{F'}{\pi(R_n'^2-R_0'^2)}=\frac{W-w'_1}{W}\times\frac{\pi\rho_0{}^2P_0-R_e}{\pi(R_n'^2-R_0'^2)}. \qquad (76)$$

This force acts only in the plane of the instantaneous center of longitudinal pressure of the screw-box liner against the threads of its housing. From this point forward the stress decreases as far as the yoke shoulder. At the yoke shoulder it suddenly changes, however, and the only force acting becomes that of the inertia of the mass forward of any section considered. If this mass is taken equal to $\frac{w'_2}{g}$, where w'_2 is the weight of the gun forward of the section considered, the total stress is

$$F=\frac{w'_2}{g}\times\frac{dv}{dt}.$$

It is useless to attempt to calculate the exact unit stress in any layer because the gun is not a homogeneous tube and we cannot state the relations between the stresses of the various elements. The work is unnecessary, however, because the total force is small and may be neglected.

247. Gun projects.—The preliminary design of a gun is called a *project*. It includes tentative sketches and rough computations as to maximum strength, muzzle velocity, and chamber capacity.

When it has been decided that a gun of a new type is needed the general requirements of such a type are tentatively fixed and the project commenced. For instance, suppose that a new gun is desired, the progress in artillery having reduced the comparative value of the existing type. Progress being usually along lines of greater power, reduction of erosion, ease of operation, rapidity of fire, or increase in striking energy, it is probable that as many improvements as possible along each of these lines will be incor-

porated in the new gun. The caliber is first settled upon, and then the approximate length in calibers. In the case of small guns the muzzle velocity is tentatively fixed, but since erosion is proportionately larger for large guns it usually seems more desirable in the case of large calibers to fix the limit of pressure and with that pressure to get as high a velocity as possible. Several sets of computations are made with variations of the chamber capacity and powder characteristics until a proper combination is secured.

Suppose it is required to design a 12-inch 50-caliber gun. With the three elements of caliber, length, and powder pressure several chamber capacities are chosen and calculations made as to the effects of several powders in them. From previous experience as to the limits of allowable densities of loading the weight of powder to be used is approximated and then the various elements varied until several reasonable combinations of chamber capacity, weight of charge, muzzle velocity, and maximum pressure have been obtained.

For several years the allowable densities of loading have risen in value, due to the use of more progressive powders and the tendency toward a reduction in the size of chambers for a given power. It is desirable to have a short chamber so as to lose as little of the travel of the projectile as possible and also to get more uniform ignition, and to have a small chambrage in order that the outside dimensions of the gun need not be too great. As a general rule, though a rule that is departed from without hesitation, it may be stated that the length of the chamber is usually between 6 and 7 calibers, and the chambrage is about 1.20. At least the ratio of chamber length to chambrage is kept near these approximate proportions.

The general design and method of attachment of the screw-box liner are selected. Its length has usually been fixed at about one caliber, but the tendency at present seems to be toward an increase in this dimension. An attempt is made to eliminate defects that may have appeared in previous designs.

Several drawings are now made of the project. The length in all cases is equal to the length in calibers times the caliber plus the length of the screw box.

So many variables enter into a design that experience, based on a sound understanding of the principles of gun construction, can be

the only safe guide. The consequences of the bursting of a gun in service are so grave that all possibility of such an accident must be avoided, and yet the gun must not be made excessively heavy nor of a form that cannot be mounted in turrets that have proved the most satisfactory. Experience has shown the general form a gun must take to give the best results with the powders in use at present, and no radical changes in this form can be made without inviting certain disaster. With any new design it is attempted to retain the advantages of previous types and to eliminate any defects that have shown up in service or may seem to be indicated by carefully tested theories. Therefore, in laying down a gun the previous designs are closely followed so far as regards the general outline, thickness and length of elements, mode of attachment of the various parts to each other, manner of assembly and approved practice in general where it appears to answer the purpose. The radical change of too many variables being inadmissible, it follows that progress is necessarily slow, and that at one stroke all previous defects may not be eliminated and a gun produced that will be perfect for all future time.

With these considerations in mind the outline of the new gun will follow closely the outline of a previous gun that seems best adapted to the purpose; changes in the outer dimensions will be made where it seems necessary and thus the form of the gun will be arbitrarily fixed. It may be that a gun of the same caliber will not be chosen as a pattern, but one of a smaller or larger caliber type that seems to have fulfilled certain of the requirements for the new type.

For two reasons the breech cylinder over the powder chamber is usually larger than the slide, which is also cylindrical. The first reason is that the chamber diameter under the breech cylinder is larger than the bore diameter under the slide cylinder, and there must therefore be an increased outside diameter for strength. The second reason is that if the gun is heavier at the breech its center of gravity will be farther from the muzzle and a smaller length need be put inside the turret. The gun usually has an approximately constant slope from the slide cylinder to the neck cylinder just in rear of the muzzle; the muzzle bell is also a frustrum of a cone similar to previous types.

The question then arises as to the number of layers of metal to use. Generally large calibers have either four or five layers: four

if the tube is later to be bored for the insertion of a liner and five if the liner is to be included in the gun as originally built. This rule is by no means rigid, however, as witness the 14-inch Mark IV gun with four layers, liner included. The practice most in favor at the present time is to build five-layer guns with a liner tapered from breech to muzzle for easy removal.

The problem now is to apportion the metal among four layers, the inner and outer radii being given. For the greatest theoretical transverse strength the law of thickness requires that if R_0, r, R_1, R_2 and R_3 are the respective radii from the bore outward, they must be connected together by the following relations:

$$r^2=R_0R_1, \quad R_1^2=R_2r, \quad R_2^2=R_1R_3.$$

These ratios may not be rigidly adhered to for the following reasons:

1. For large-caliber guns the breech diameter of the liner must be great enough to allow for at least three shoulders having a height of from 0".2 to 0".25 and the proper taper and yet leave sufficient metal at the muzzle for rigidity and for the prevention of creep due to the mandrelling effect of the projectile.

2. It is desirable to have a heavy tube so as to provide rigidity for the gun and so prevent droop of the muzzle.

3. The layer carrying the screw-box liner must have enough additional thickness to provide for taking the longitudinal stresses without impairing the transverse resistance of the gun. The usual rule is to compute this layer for longitudinal strength and then make it from 2.5 to 3 times as thick as necessary to carry the longitudinal stress. The extra thickness is taken about equally from the contiguous layers on both sides. The calculation for strength is usually made by equation (75).

4. The thickness of the outside layers must not be so great that it will be impossible to get good forgings.

5. Sudden and great changes in the diameter of the gun or its component parts must be avoided.

It is apparent that in the case of a large gun with a large number of elements, as, for instance, the Mark VII 12-inch 50-caliber gun, which is in 12 parts, considerable juggling will be necessary before the above conditions can be satisfied and yet obtain sufficient transverse strength.

Having decided upon the various diameters near the breech, at the forward end of the slide cylinder, and at the neck, the related questions of the manner of assembly and the character of the joints and shoulders are taken up. The following principles in this connection must be rigidly observed:

1. Joints must be of such a character as to allow the elements to be easily assembled.

2. The tube and liner must be locked to prevent crawl, and all other elements must be locked both ways to prevent movement in either direction.

The tube and liner are so long that ordinarily the shrinkage friction will prevent rearward motion, but shoulders must be provided to keep them from going out at the muzzle.

Locking is accomplished by means of locking rings, locking hoops, and shoulders. Locking rings are relatively short and thin rings either hooked or screwed to the elements of the gun; they are not assembled with shrinkage and do not contribute to the transverse strength. Locking hoops ordinarily attach to the other elements by hook joints and are assembled with shrinkage; they are longer and heavier than the rings.

Shoulders are turned on an element to prevent relative longitudinal movement between it and the element shrunk over it. The distance between shoulders varies as experience dictates. Their height may be from 0".2 to 1".0, the usual height being about 0".5 where possible. As a general rule two shoulders are not put in the same transverse plane, because a plane of rupture is most likely to form at a shoulder, and it is best to scatter the weakest parts so that one plane will not include the weak points of several layers. The same rule is followed in the case of joints.

Butt joints are avoided when it is possible to use a lap joint. The latter are preferable because they distribute the weakness over a greater length, they assist locking and contribute to the stiffness. Joints at the outside of the gun in particular must be designed so as to prevent droop, as droop is due partly to stretch of the metal and partly to working at the joints.

The several drawings are worked up to embody the various ideas that have been expressed. If there are three drawings, for example, one may show a heavy gun, one a light gun, and one a gun of medium weight, and in each the arrangement will be slightly

different. Possibly one drawing will be of a four-layer unlined gun, one of a four-layer lined gun, and one of a five-layer lined gun. Or, in one the joints and layers may be arranged according to previous designs and in one they may be laid down on a new plan. During their construction the drawings are subjected to continuous criticisms and change and new ideas are included as they may occur to those in charge of the project.

Finally, after several weeks' work, when the various projects seem to answer the requirements determined upon, the total weight, location of the center of gravity, and an approximate strength curve are computed for each. They are then submitted for decision and final criticism.

Usually one of the projects is decided upon, though it may be desirable to make a few minor changes in it. The exact chamber is definitely selected and, as a rule, the maximum bore pressure and the muzzle velocity are fixed, together with the desired weight of charge. Orders are then issued for the definite working up of the design, and a decision is made as to whether the batteries of one or more ships are to be built at once or a type gun only. It is the usual practice to build a type gun when a new caliber is in question or when the changes have been numerous and radical as compared with existing guns.

A Mark is then assigned to the design selected.

As a rule, the drawings are worked up in the following order:

1. Shrinkages, strength, velocity, and pressure curves.
2. General arrangement.
3. Details.
4. Chamber and breech.
5. Rough forgings.
6. Shrinkage sheet.
7. Center of gravity for shrinkage pit.
8. Rifling.

Other drawings may sometimes be required, but these drawings are always made, though not always in the above order.

The breech-mechanism drawings and computations constitute an entirely separate set.

Section VIII.—Gun Computations.*

248. Preliminary computations.—A pencil drawing of the gun is laid down and the sections selected for strength computations. These sections vary in number according to the gun; in some cases they are as many as 28. In the case of the gun selected for the purposes of illustration, the Mark VI, Modification 3, 12-inch 50-caliber gun, computations were made at 24 sections. The sections are numbered in Roman numerals, the lowest number being near the breech.

The principle governing the selection of sections may be generally stated as follows: "Computations must be made for every plane of the gun having a strength different from that of the planes on either side of it, and where there is reason to believe a sudden change in strength occurs, on both sides of the change and close to it." The plotted results of the computations must give a continuous strength curve from breech to muzzle.

In order to reduce the immense amount of labor involved in the case of a gun of large caliber, the computations are made on printed forms. The Birnie formulas, involving the introduction of subsidiary constants, are used. These are the same as those given in this book by Professor Alger, but arranged for greater convenience and known as the "Reduced Formulas." For a thorough understanding of their meaning it would be necessary to deduce each one from the fundamental equations; this work is not given here as it is easy enough, though long.

In considering these forms we find various methods used that are not those that we have been accustomed to. It is important to know the formulas on which the forms are based. Logarithms are denoted by letters only. An expression such as a_3 (θ_3) indicates that a_3 is to be multiplied by θ_3; therefore their logs are to be added. This is further indicated by a + sign after θ_3. This method is used throughout. Expressions are denoted by letters or numerals and are thereafter always referred to by such letters or numerals. The pressures in the state of rest are denoted by P' instead of $\bar{P}$ as in this text-book.

Sheets 2, 3 and 4 are used for the preliminary computations and Sheet 6 for the final computations.

* Written by Lieutenant (j. g.) R. K. Turner, U. S. Navy at the Naval Gun Factory, February, 1916.

It sometimes happens that the dimensions of the gun as laid down in the pencil drawing do not give sufficient strength, or that a very sudden break in the curve is caused by an improperly designed joint. To correct these faults new dimensions are tentatively assigned or the faults at the joint in question corrected. The strength is then computed with the new dimensions.

249. Computation forms.—Sheet 1 of the computations is headed " Constants depending on fixed radii and constant modulus of elasticity " and gives the values of the radii and their various combinations with each other, together with the logarithms.

Sheets 2 and 3 are headed " Computations for reduced formulas and maximum values," and " Computations for reduced formulas and maximum values corrected," respectively, and give the logarithmic forms for computing:

1. The maximum elastic forces $P_m(\theta_m)$ and $P_m(\rho_m)$ (for any layer m).
2. A function $l_m(P_m)$ of the variations of pressures between the state of action and rest.
3. The pressures, state of rest, P_m'.
4. The initial limiting pressure on the tube, P_1'.
5. The adopted values of $P_0(\theta_0)$ and $P_0(\rho_0)$ corresponding to the minimum of P_1'.
6. P_m' corresponding to the minimum P_1'.

$P_m(\theta_m)$ is the pressure at any surface that will bring the metal to its limit of elastic tangential strain at that surface, while $P_m(\rho_m)$ is the pressure that will bring the metal to the elastic limit of radial strain. If the pressure is greater than $P_m(\theta_m)$ the metal will actually be permanently stretched tangentially and may even crack if the ultimate strength is passed. On the other hand if the pressure is greater than $P_m(\rho_m)$ without being greater than $P_m(\theta_m)$ the metal will crush slightly and so enlarge the bore, but its tangential tenacity, upon which the actual stability of the gun depends, will in no way be affected; in other words, $P_m(\rho_m)$ may be exceeded without any other effect than a slight increase in the diameter of the bore, so long as the metal at the outside of the layer is not strained in the same way beyond its elastic limit. This increase in the bore diameter will be very slight and is therefore never considered in the case of the inner layer, so that $P_0(\theta_0)$ is always used instead of $P_0(\rho_0)$, no matter which is the smaller. It will be otherwise with the other layers, however, because it is

apparent that any increase in the bore diameter of any layer except the first will reduce the shrinkage of that layer, and will therefore decrease the possible range of working of the inner layers, thus reducing the elastic tangential resistance. The only layer this does not apply to is the outer, since there $P_{n-1}(\rho_{n-1})$ is always less than $P_{n-1}(\theta_{n-1})$. Therefore the following rule is adopted in computing the successive values of $P_m(\theta_m)$ and $P_m(\rho_m)$: "For computing the successive values of $P_m(\theta_m)$ and $P_m(\rho_m)$ always use the smaller of the two quantities, $P_{m+1}(\theta_{m+1})$ and $P_{m+1}(\rho_{m+1})$."

The function $l_m(p_m)$ is obtained from the formula

$$l_m(p_m) = \frac{R_m^2(R_n^2 - R_{m+1}^2)}{R_{m+1}^2(R_n^2 - R_m^2)}$$

and is used for the purpose of computing the variations in pressures, p_m. The latter is computed with the formula:

$$p_{m+1} = p_m \times l_m(p_m)$$

and the pressure, state of rest, from

$$P_m' = P_m - p_m.$$

The initial limiting pressure on the tube is determined by that pressure, P_1', which the tube will sustain in the state of rest without passing the elastic limit of compression, since it has been shown in the deduction of the formulas (equation 24) that the dangerous strain, in a tube subjected to external pressure only, occurs at the inner surface and is a tangential compressive strain. If the tube is not to be bored for a liner the first of the two formulas, that for finding ρ_0', is not used, but the second formula only, ρ_0' being taken equal to ρ_0 and R_0 equal to the inner radius of the tube. Both formulas must be used if the tube is to be bored for a liner.

The "Pressures, state of rest, relieving jacket" give first the computation of the pressures in the state of action at the inner surface of the jacket, using the minimum value of P_1', and then the pressures in the state of rest in the outer layers of hoops that will be required to produce the maximum pressures for the state of action when the variations in pressures have been reduced proportionately to the reduction in P_0. In other words:

$$P_m' = P_m'(\text{max.}) - p_m.$$

This will subject the two outer layers to the maximum elastic stress and will reduce the maximum stress in the jacket. Thus all

the layers will not participate proportionately in the transverse work, and it may happen, when the working limits on Sheet 4 are figured, that the metal of the jacket will be found to be strained beyond its elastic limit in the state of rest. In this case it will be necessary to reassign values of P_m' to the outer hoops to make the proper adjustments. Therefore this is essentially a trial method and may entail a great deal of additional labor. For this reason the set of approximate formulas under " Pressures, state of rest, corrected, relieving hoops " were adopted and are ordinarily used. These formulas relieve the pressures, P_m', on the outer hoops proportionately to the reduction in P_1' and differ from the theoretically correct pressures by negligible amounts, a small constant term having been omitted in the derivation of each of the formulas. When using this method one may be sure of getting values of P_m' that will not over-compress the jacket in the state of rest, though the total maximum resistance of the gun may be very slightly reduced. The jacket is thus made to do its proper share of the work, which is desirable, unless there are special reasons to the contrary, as, for instance, when the screw-box liner is attached only to a comparatively thin jacket.

Sheet 4 gives the " Computations for reduced formulas, shrinkages, and compression of the bore," using the adopted pressures, state of rest, corrected, P_m'. The formulas are self-explanatory.

Sheet 5 is a summary of the reduced formulas and a tabulation of the values of the subsidiary constants a_n, b_n, c_n, etc. This sheet is no longer used, however, as it consumes more time than it saves. In its place has been substituted Sheet 7, with one set of values omitted, viz., the " Relative shrinkages." This space is then used for writing in the " adopted " shrinkages in the adjustment of shrinkages. As Sheet 7 gives the absolute values of all the quantities required, instead of their values in terms of the subsidiary constants, it is much easier to visualize all the conditions obtaining at the various sections and thus gain a clearer viewpoint for the proper adjustment of shrinkages.

In general the preliminary computations may be considered complete with the completion of Sheets 1, 2, 3 and 4.

250. Adjustment of shrinkages.—When the preliminary computations have been finished the values for all sections are tabulated on Sheet 7 as outlined above. It may be noted that the absolute shrinkages come out to six or eight places of decimals, though

it is known that it is necessary to allow a plus or minus tolerance of about .0005 inch, since large machine turning cannot be done more accurately than that. It is obvious, therefore, that the assigned shrinkage can only be given to thousandths of an inch and a total tolerance range allowed of .001 inch.

It will be found that the shrinkages often change their value abruptly when computed for maximum strength, and since it is not desirable to cut a large number of shoulders on the various elements the change must be made gradually in the form of a cone. Also, for the sake of economy and accuracy, it is better to have one shrinkage extend over the greatest possible length of the surface of the element. There are many other practical aspects of the subject of shrinkage, as, for instance, the fact that a heavy shrinkage must not be put on a thin section either for fear of overstraining the metal or because it is obvious that it will not hold the shrinkage until the next envelope is in place. All the various considerations are the result of experience and therefore the assignment of shrinkages can follow no definite rules that will be applicable to all cases.

In general, however, shrinkages are assigned the same value over as long a surface as possible and the value expressed to the nearest thousandth of an inch below the minimum theoretical shrinkage for that surface. The various contact surfaces are considered in order beginning at the inner, and their relation to each other must be understood in order to assign proper values. For instance, if the theoretical shrinkages are

$$S_1 = .0016, \quad S_2 = .0483, \quad S_3 = .0571,$$

it is at once apparent that S_1 must be made greater than .0016, because the tube and jacket will not hold together under so small a pressure as will result from the use of this shrinkage. Therefore a larger value of S_1 is chosen and S_2 and S_3 decreased so that the pressure at the outer surface of the layers in the state of rest will not be too great. In this case shrinkages might be assigned as follows:

$$S_1 = .012, \quad S_2 = .040, \quad S_3 = .047.$$

A reassignment will be made if these values are shown to be unsuitable by the computations on Sheet 6.

One other general principle of shrinkage is that it is desirable to work the tube higher than the outer layers; in other words, the tube is to be considered the limiting layer.

251. Final computations.—The final computations are made on Sheet 6 and the results tabulated on Sheet 7, together with the maximum theoretical pressures found on Sheets 2, 3 and 4. From these tabulated values are constructed the curves of tangential and radial resistance and relative compression of the bore.

Sheet 6 shows the assumed values of the shrinkages and gives the forms for the logarithmic computation of values of the compressions, the pressures P_m' and P_m, and the tangential compression resulting from the use of the assigned shrinkages.

In addition to the formulas for finding the necessary quantities are a considerable number of check formulas obtained by the transposition of the regular formulas. For instance, there are three sets of computations for "Working limits," one for checking the theoretical values of $P_m(\theta_m)$ and $P_m(\rho_m)$, one for checking the assumed values of $P_m(\theta_m)$ and $P_m(\rho_m)$, and one for checking the values of those quantities after the assumed values of the shrinkages have been used. The formulas for "Working limits" give the effective values of θ_m and ρ_m when the various values of $P_m(\theta_m)$ and $P_m(\rho_m)$ are used, and in all cases these values must be equal to or lower than the respective limits of extension and compression for the layer under consideration, except in the case of the inner layer, where ρ_0 may exceed the elastic limit. If, for instance, the true value of θ_m is 60,000 and we get a value of $\theta_m = 50{,}000$ from the computation of the working limits, the layer could be replaced by a layer whose elastic limit of extension is 50,000 without reducing the height of the strength curve, and therefore all the total available strength of the layer will not be used when the bore pressure becomes equal to the adopted value of P_0. But if the values of θ_m or ρ_m are greater than the elastic limits either an error has been made or new values of P_m must be chosen.

252. Computations for the liner.—When a liner is to be originally inserted in the gun it is assembled after the rest of the gun has been built up. In this case computations as to its effect on the other layers are made, the original computations being essentially what would be required for a gun with a bore diameter equal to the inner diameter of the tube.

The formulas are based on the assumption of a two-layer gun, the tube, jacket, and hoops forming the outer layer and the liner the inner layer. The formulas may be deduced from the theoretical formulas for a two-layer gun assembled with the shrinkage

assigned for the liner. This shrinkage is small because it is desirable to be able to remove the liner and insert a new one without having to bore it out. There is also a possibility of the liner's sticking during assemblage if the shrinkage is very great, since the assembled gun must not be heated to too high a temperature for fear of disassembly of the elements.

The computations are arranged on two sheets, Nos. 8 and 9. It must be understood that so far as the constants are concerned, the liner is treated as a regular layer, R_0 being the bore radius and R_1 the outside radius of the liner.

Sheet 8. Assumed Shrinkage $=S_1$.

Pressures, state of rest, at R_1.—A pressure P_1' on the outside of the liner is caused by putting in the liner with a shrinkage S_1.

$$P_1' = \frac{S_1}{h_1} = S_1 \times \frac{E(R_1^2 - R_0^2)(R_n^2 - R_1^2)}{2R_1^2(R_n^2 - R_0^2) \times D_1}.$$

Change of pressure in state of rest.—These formulas give the increase of pressure at the various surfaces that result from the insertion of the liner, this causing a pressure of P_1' at the inner surface of the tube where no pressure existed before.

$$p_2' = P_1' l_1, \quad p_3' = p_2' l_2, \quad p_4' = p_3' l_3.$$

Pressures, state of rest.—The addition of the increase of pressures in the state of rest to the *original* pressures before the insertion of the liner gives the new pressures, state of rest, at the contact surfaces.

$$P_2' = p_2' + P_2'(\text{original}),$$
$$P_3' = p_3' + P_3'(\text{original}),$$
$$P_4' = p_4' + P_4'(\text{original}).$$

Tangential compression of bore.—$T\rho_0$ is the tangential compressive stress caused at the inner surface of the liner in the state of rest by an outside pressure of P_1'.

$$T\rho_0 = \frac{2R_1^2 P_1'}{R_1^2 - R_0^2}.$$

Strength of gun limited by liner.—The curve drawn through the plotted values of P_0 will be the curve of tangential resistance of the gun when the stress in the liner has a value of θ_0.

$$P_0 = \frac{3(R_n^2 - R_0^2)}{4R_n^2 + 2R_0^2}(\theta_0 + T\rho_0).$$

Variation of pressures.—When the gun is fired and a pressure P_0 brought into existence in the bore it causes the increase of pressure P_m at the other contact surfaces.

$$p_1 = l_0 P_0, \quad p_2 = l_1 p_1, \quad p_3 = l_2 p_2, \quad p_4 = l_3 p_3.$$

Pressures, state of action.—P_m is the algebraic sum of the pressures, state of rest, and the increase of pressure p_m. The latter quantity is considered positive in the present case, since it is one of tension with respect to P_m'.

$$P_1 = P_1' + p_1, \quad P_2 = P_2' + p_2, \quad P_3 = P_3' + p_3, \quad P_4 = P_4' + p_4.$$

Working limits.—θ_m and ρ_m are the stresses in the various layers when a pressure P_0 is caused in the bore.

$$\theta_3 = \frac{P_3(\theta_3)}{a_3},$$

$$\theta_2 = \frac{P_2(\theta_2)}{a_2} - P_3 \times \frac{b_2}{a_2} \qquad \rho_2 = \frac{P_2(\rho_2)}{c_2} - P_3 \times \frac{d_2}{c_2},$$

$$\theta_1 = \frac{P_1(\theta_1)}{a_1} - P_2 \times \frac{b_1}{a_1} \qquad \rho_1 = \frac{P_1(\rho_1)}{c_1} - P_2 \times \frac{d_1}{c_1},$$

$$\theta_0 = \frac{P_0(\theta_0)}{a_0} - P_1 \times \frac{b_0}{a_0} \qquad \rho_0 = \frac{P_0(\rho_0)}{c_0} - P_1 \times \frac{d_0}{c_0}.$$

When an old gun is to be relined, computations for the liner are made in accordance with a somewhat similar set of formulas, the chief differences being: 1st, that now r represents the outer radius of the liner and R_1 the outer radius of the tube; and 2d, that several additional formulas are necessary to show the changes in the pressures, state of rest, at the various contact surfaces that will result when the tube is bored and the liner inserted.

253. Example of gun computations.—The Mark VII, Modification 3, 12-inch 50-caliber gun has been selected for the purposes of illustration, the results being given in the case of the section over the chamber, number IV. This is an unlined gun, but provision has been made for the insertion of a conical liner after the inner surface of the tube has been worn out.

It will not be necessary to give the formulas used, as they may be obtained directly from the computation sheets. The results only will be given:

In this case:

$R_0 = 15.20$ $r = 17.083$ $R_1 = 19.75$ $R_2 = 26.0$
$R_3 = 34.0$ $R_4 = 44.0$ $E = 30,000,00$
$\theta_0 = \rho_0 = 55,000$ $\theta_1 = \rho_1 = 60,000$ $\theta_2 = \theta_3 = \rho_2 = \rho_3 = 65,000$

The elastic limits are the specified values, the actual values not being used because it would be impossible and undesirable to construct strength curves for each individual gun, one set of curves being computed that will apply to all, provided they meet the specifications.

The subscript m will be used to show that a quantity may apply to any layer.

PRELIMINARY COMPUTATIONS.

SHEET 2. COMPUTATIONS FOR REDUCED FORMULAS AND MAXIMUM VALUES.

1. *Maximum pressures.*—Theoretically possible.

$P_3(\theta_3) = 15,056$ [Use $P_3 = P_3(\theta_3)$]
$P_2(\theta_2) = 33,217$ $P_2(\rho_2) = 39,293$ [$P_2(\theta_2) < P_2(\rho_2)$ Use $P_2 = P_2(\theta_2)$]
$P_1(\theta_1) = 53,442$ $P_1(\rho_1) = 50,095$ [$P_1(\rho_1) < P_1(\theta_1)$ Use $P_1 = P_1(\rho_1)$]
$P_0(\theta_0) = 70,948$ $P_0(\rho_0) = 59,479$

2. *Working limits.*—Check for accuracy of computations for (1).

$\theta_3 = 65,000$ $\theta_1 = 60,000$ $\rho_1 = 60,000$
$\theta_2 = 65,000$ $\rho_2 = 65,000$ $\theta_0 = 55,000$ $\rho_0 = 55,000$

3. *Variations of pressures.*—Computation of $l_m(p_m)$.

$l_0(p_0) = (\bar{1}.73004)$ $l_1(p_1) = (\bar{1}.67236)$ $l_2(p_2) = (\bar{1}.55872)$

SHEET 3. COMPUTATIONS FOR REDUCED FORMULAS AND MAXIMUM VALUES, CORRECTED.

4. *Pressures, state of rest.*—Theoretically possible.

$p_1 = 38,105$ ($P_0(\theta_0)$ has been used for the reasons given in §79.)
$p_2 = 17,920$ $p_3 = 6,487$
$P_1' = P_1 + (-p_1) = 11,990$ $P_2' = P_2 + (-p_2) = 15,297$
$P_3' = P_3 + (-p_3) = 8,569$

The minimum values of P_m are used for the reasons given in §79. The quantity p_m carries the minus sign because it is negative as compared to P_m.

5. *Initial limiting pressure on tube.*—This is the value of the maximum P_1' that will allow the tube to be bored for the liner without collapsing. The formulas are based on the assumption of a two-layer gun.

$$\rho_0' = 53,166, \quad P_1' = 10,838.$$

It will be noted that the P_1' given by (4) is greater than that found here, therefore the latter value will be used for correcting the maximum allowable pressures.

6. P_0 *corresponding to* P_{n-1}'.—Check for "Variations of Pressures" and "Pressures, State of Rest."

$$P_0 = 70,948.$$

7. P_0 *corresponding to* $P_1 + (-p_1)$.—Computation of subsidiary constants, check for P_1', and computation of radial resistance when $P_0(\theta_0)$ (theoretical) is used.

$$P_0(\theta_0) = 70,949,$$
$$P_0(\rho_0) = 52,405.$$

It may be noted that the $P_0(\rho_0)$ found here is less than the theoretical $P_0(\rho_0)$; this will always be the case when $P_0(\theta_0) > P_0(\rho_0)$ as found on Sheet 2.

8. *Pressures corrected.*—This gives the maximum theoretical $P_0(\theta_0)$ and $P_0(\rho_0)$ using the minimum of the two values of P_1', and the maximum variations in pressures corresponding to the adopted value of P_0. If the initial limiting pressure on the tube is not found, this computation is unnecessary.

$P_0(\theta_0)$ adopted $= 67,425$ $\quad P_0(\rho_0)$ adopted $= 51,081$
$p_1 = 36,213$ $\quad P_0(\theta_0)$ (adopted) is used for the reason given in §79.
$p_2 = 17,030$ $\quad p_3 = 6,165$

9. *Pressures, state of rest, relieving jacket.*—See explanation of this and the following set of formulas in §249. It may be noted that only the first of the three following formulas has been used, so as to obtain the pressure, state of action, at the outer surface of the tube corresponding to P_1 (min.). The hoops and not the jacket have been relieved in this gun.

$$P_1 = 47,051.$$

10. *Pressures, state of rest, relieving hoops.*—These now become the preliminary adopted values of the pressures in the state of rest on the jacket and *C*-hoop.

$$P_2' = 14,537, \quad P_3' = 8,209.$$

SHEET 4. COMPUTATIONS FOR REDUCED FORMULAS, SHRINKAGES, AND COMPRESSION OF BORE.

11. *Shrinkages.*—The shrinkages here found are those necessary to give the adopted pressures in the state of rest.

$$S_1 = .0092153, \quad S_2 = .039499, \quad S_3 = .050832.$$

12. *Compressions of bore.*—δ_1, δ_2 and δ_3 are the partial relative bore compressions that result from the successive shrinkage of the three outer layers, and the final relative compression is their sum. The same applies to Δ_m, the absolute compressions.

$$\delta_1 = .00029984 \qquad \Delta_1 = .0045575$$
$$\delta_2 = .00078837 \qquad \Delta_2 = .011983$$
$$\delta_3 = .00068397 \qquad \Delta_3 = .010260$$
$$\delta_0 = \delta_1 + \delta_2 + \delta_3 = .00177218$$

13. P_1' corresponding to δ_0.—This is a check for (12).

$$P_1' = 10.838.$$

14. *Tangential compression.*

$$\rho = 53.166.$$

ρ should equal the elastic limit of the metal if the theoretical values of P_1' has been used. If a lower value has been adopted such that the bore of the tube will not be compressed to the elastic limit in the state of rest, ρ will be less than θ_0.

15. *Working limits.*—The values of θ_m and ρ_m are the *effective* elastic limits as defined in §251. They are introduced as a check on the accuracy of the preceding work, and to find the relative participation of the layers after the outer layers have been relieved so that the tube will not be over-compressed when bored for the liner. It may be noted that θ_0 equals the allowed elastic limit, while ρ_0 greatly exceeds this limit; this is in accordance with what has been said in §249. In the case of the other layers neither θ nor ρ may exceed the proper elastic limits. The ratios of θ_m found here to the allowed θ_m show the relative participation of the various layers.

$$\theta_0 = 55{,}000 \quad \rho_0 = 78{,}270 \quad \theta_2 = 61{,}770 \quad \rho_2 = 48{,}649$$
$$\theta_1 = 41{,}842 \quad \rho_1 = 55{,}770 \quad \theta_3 = 61{,}772$$

Sheet 5 is no longer used, but Sheet 7 instead. This will be called Sheet 7a.

FINAL COMPUTATIONS.

Sheet 7a is for the adjustment of shrinkages. As the shrinkages are adjusted with relation to the other sections, the shrinkages for Sections II to IX are tabulated below to show the method used.

THEORETICAL ABSOLUTE SHRINKAGES.

Shrinkage.	Section.							
	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
S_1	← .024954	← .0092313	.0092153	.010705	.010428 →	← .013466	.01258 →	← .012470
S_2	..	← .039574	.039499 →	← .039415	.039428	.039075	.039462	.037567 →
S_3	....	.050773	.050832	.050822 →	← .049281	.049194	.049550	.047698

The small arrows indicate the presence of a shoulder between the two sections where they occur. Thus the tube has a shoulder between Sections VI and VII.

From what has been said before it is at once apparent that it would be impossible to obtain these theoretical shrinkages on account of their wide variations and it would therefore be useless and bad practice to assign them. The first thing to do is to examine this table carefully and then by balancing the various considerations governing the adjustment of shrinkages finally arrive at a logical conclusion.

S_1 for Section II, where there are two layers only, may at once be given a value of .025.

From Sections III to VI S_1 varies from .0092313 to .010428. In no case may these shrinkages be exceeded without over-compressing the tube when bored for the liner, so that a proper value of S_1 for these sections seems to be .009. For the same reasons S_1 from Sections VII to IX is given a value of .012.

Proceeding in this way from one surface to another the shrinkages are relieved slightly in every case, until finally the shrinkages as given in the table below are tentatively adopted.

ASSIGNED SHRINKAGES.

Shrinkage.	Section.							
	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
S_1	.025	....	.009	....	....	.012	....	.012
S_2	..	..	.039	....	.037	....	....	....
S_3	....	...	.050	....	....	.047	...	....

The assigned shrinkages must now satisfy the conditions that the tube will not be over-compressed when bored for the liner and that no metal in the gun is strained beyond its elastic limit. Whether it fulfils these conditions is determined in the computations on Sheet 6.

As a matter of fact the shrinkages finally assigned to Section III were $S_1 = .009$, $S_2 = .025$ and $S_3 = .025$, because the cross-strains due to the heavy longitudinal stresses at that section made it advisable to relieve the tangential strains that would have occurred if the values given in the table had been used.

When a large change in the assigned shrinkages occurs at a section the change is made gradual by the use of a coned surface. This method is shown in the small figure in the lower left-hand corner of the drawing of the strength curves, etc.

SHEET 6. COMPUTATIONS FOR ADJUSTED VALUES.

These formulas are similar to those on Sheets 2, 3 and 4, except that the subsidiary constants do not have to be computed, and the correction and most of the check formulas may be omitted.

16. *Assumed values.*

$$S_1 = .009, \quad S_2 = .039, \quad S_3 = .050.$$

17. *Shrinkages and compressions.*—Computations are made using the assumed value of S and subsidiary constants from Sheet 4.

$\phi_1 = .00045569$	$\delta_1 = .00029283$	$\Delta_1 = .0044510$
$\phi_2 = .0015000$	$\delta_2 = .00077841$	$\Delta_2 = .011832$
$\phi_3 = .0014706$	$\delta_3 = .00067279$	$\Delta_3 = .010226$
	$\delta_0 = .00174403$	

18. *Pressures, state of rest.*—These are computed from the relative compressions and certain subsidiary constants obtained from Sheet 4.

$$P_3'=8{,}075, \quad P_2'=14{,}328, \quad P_1'=10{,}665.$$

19. *P_1' corresponding to δ_0.*—Check for (17) and (18).

$$P_1'=10{,}665.$$

The value of P_1' must not be greater than the "Initial limiting pressure on tube" found on Sheet 3.

20. *Tangential compression.*—This must not be greater than the elastic limit of compression.

$$\rho=52{,}320.$$

21. *Pressures, state of action.*—The first five of these formulas are similar to those in (8); the remainder are those in (4) reversed.

$$P_0(\theta_0)=66{,}898 \qquad P_0(\rho_0)=50{,}883$$
$$p_1=35{,}930 \qquad p_2=16{,}897 \qquad p_3=\ 6{,}117$$
$$P_1=46{,}595 \qquad P_2=31{,}225 \qquad P_3=14{,}192$$

22. *Working limits.*—Relative participation of layers.

$$\theta_0=55{,}000 \qquad \rho_0=77{,}796$$
$$\theta_1=41{,}610 \qquad \rho_1=55{,}286$$
$$\theta_2=61{,}222 \qquad \rho_2=48{,}164$$
$$\theta_3=60{,}989$$

The values of θ_m must not be greater than the elastic limit; θ will be equal to the elastic limit of the tube, while in general the values of θ for the other layers will be less than the elastic limits of those layers. ρ_0 may be greater than the elastic limit of the tube, but the values of ρ for the other layers must not be greater than the elastic limit.

SHEET 7 IS THE TABULATION OF THE COMPUTATIONS AND GIVES THE VALUES OF

Formulas No.	1.	Maximum pressures.
" "	4.	Initial maximum compression (P_1' only).
" "	5.	Limiting pressure on tube.
		Adjusted pressures.
" "	21.	a. In action.
" "	18.	b. At rest.

	Shrinkages.
Formulas No. 17.	a. Relative.
" " 16.	b. Absolute.
	Compressions of bore.
" " 17.	a. Relative.
" " 17.	b. Absolute.
" " 22.	Working limits.
" " 20.	Tangential compression.

When all the sections have been computed the curves of tangential resistance, radial resistance, and relative compression of the bore are drawn with the values of $P_0(\theta_0)$, $P_0(\rho_0)$, and δ_0, δ_1, δ_2 and δ_3 computed on Sheet 6. The curves of velocities and pressures in the bore are then drawn for purposes of comparison. It will seldom happen that any of the curves will be changed after all the sections have been computed, because the strength actually obtained for each section is compared with the requirements as soon as the computations for the section have been finished.

Plate II shows the drawings of the "Shrinkages, strength, velocity and pressure curves" for the Mark VII, Modification 3, 12-inch 50-caliber gun.

Section IX.—Formulas for the Case of Compound Cylinders of Four Layers.

254.

$$
\left.
\begin{aligned}
&(1)\quad P_3(\theta) = \frac{3(R_4^2 - R_3^2)\theta_3}{4R_4^2 + 2R_3^2}, \\
&(2)\quad P_2(\theta) = \frac{3(R_3^2 - R_2^2)\theta_2 + 6P_3R_3^2}{4R_3^2 + 2R_2^2}, \\
&(3)\quad P_1(\theta) = \frac{3(R_2^2 - R_1^2)\theta_1 + 6P_2R_2^2}{4R_2^2 + 2R_1^2}, \\
&(4)\quad P_0(\theta) = \frac{3(R_1^2 - R_0^2)\theta_0 + 6P_1R_1^2}{4R_1^2 + 2R_0^2}, \\
&(5)\quad P_2(\rho) = \frac{3(R_3^2 - R_2^2)\rho_2 + 2P_3R_3^2}{4R_3^2 - 2R_2^2}, \\
&(6)\quad P_1(\rho) = \frac{3(R_2^2 - R_1^2)\rho_1 + 2P_2R_2^2}{4R_2^2 - 2R_1^2}, \\
&(7)\quad P_0(\rho) = \frac{3(R_1^2 - R_0^2)\rho_0 + 2P_1R_1^2}{4R_1^2 - 2R_0^2}, \\
&(8)\quad [P_0] = \frac{3(R_4^2 - R_0^2)(\theta_0 + \rho_0)}{4R_4^2 + 2R_0^2}.
\end{aligned}
\right\} \quad (A)
$$

If $P_0(\theta)$ is greater than $[P_0]$, the tube will be compressed beyond its elastic limit of compression (ρ_0) by shrinkages determined with the values of $P_3(\theta)$, $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$, and so the values of one or more of the assumed elastic limits θ_3, θ_2 and θ_1 must be reduced until $P_0(\theta)$ equals, or is less than, $[P_0]$.

$$\left.\begin{aligned}
&(1)\quad S_3=\frac{2R_3}{E}\left[\theta_3+\frac{P_3(\theta)(4R_0{}^2+2R_3{}^2)-6P_0(\theta)R_0{}^2}{3(R_3{}^2-R_0{}^2)}\right]\\
&(2)\quad S_2=\frac{2R_2}{E}\left[\theta_2+\frac{P_2(\theta)(4R_0{}^2+2R_2{}^2)-6P_0(\theta)R_0{}^2}{3(R_2{}^2-R_0{}^2)}\right],\\
&(3)\quad S_1=\frac{2R_1}{E}\left[\theta_1+\frac{P_1(\theta)(4R_0{}^2+2R_1{}^2)-6P_0(\theta)R_0{}^2}{3(R_1{}^2-R_0{}^2)}\right].
\end{aligned}\right\} \quad (B)$$

In these expressions for the shrinkages, the values of θ_3, θ_2 and θ_1 are not necessarily the real elastic limits, but are the assumed elastic limits with which the finally accepted values of $P_3(\theta)$, $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$ were calculated.

$$\left.\begin{aligned}
&(1)\quad \bar{P}_3=P_3(\theta)-\frac{R_0{}^2(R_4{}^2-R_3{}^2)}{R_3{}^2(R_4{}^2-R_0{}^2)}P_0(\theta),\\
&(2)\quad \bar{P}_2=P_2(\theta)-\frac{R_0{}^2(R_4{}^2-R_2{}^2)}{R_2{}^2(R_4{}^2-R_0{}^2)}P_0(\theta),\\
&(3)\quad \bar{P}_1=P_1(\theta)-\frac{R_0{}^2(R_4{}^2-R_1{}^2)}{R_1{}^2(R_4{}^2-R_0{}^2)}P_0(\theta).
\end{aligned}\right\} \quad (C)$$

These are the pressures at the surfaces of contact *in the state of rest*, $P_3(\theta)$, $P_2(\theta)$, $P_1(\theta)$ and $P_0(\theta)$ being the values of the pressures in the state of action used in calculating the assigned shrinkages.

$$\bar{e}_t(R_0)=-\frac{R_2{}^2-R_1{}^2}{R_2{}^2-R_0{}^2}\frac{S_1}{2R_1}-\frac{R_3{}^2-R_2{}^2}{R_3{}^2-R_0{}^2}\frac{S_2}{2R_2}-\frac{R_4{}^2-R_3{}^2}{R_4{}^2-R_0{}^2}\frac{S_3}{2R_3}. \quad (D)$$

This is the circumferential strain at the surface of the bore caused by the superposition of the three outer layers with their respective shrinkages S_1, S_2 and S_3, the successive terms being the three circumferential strains produced by the three successive layers. $2R_0\bar{e}_t(R_0)$ is the change of diameter (contraction) of the bore from its free state to that of complete assemblage of the system and $-E\bar{e}_t(R_0)$ is the circumferential compression of the bore in the state of rest.

The radial strain at the surface of the bore in the state of rest is $\bar{e}_p(R_0)=-\frac{1}{3}\bar{e}_t(R_0)$, so that it is under a true tension radially one-third as great as its circumferential compression. Therefore

the real elastic strength of the system when assembled with shrinkages S_1, S_2 and S_3 is the least of the two following values of P_0:

$$\left.\begin{aligned}(1)\quad P_0^{(1)}&=\frac{3(R_4^2-R_0^2)}{4R_4^2+2R_0^2}\,(\theta_0-E\bar{e}_t(R_0)),\\ (2)\quad P_0^{(2)}&=\frac{3(R_4^2-R_0^2)}{4R_4^2+2R_0^2}\,(\rho_0-\tfrac{1}{3}E\bar{e}_t(R_0)).\end{aligned}\right\}\qquad\text{(E)}$$

In these expressions it is important to note that $\bar{e}_t(R_0)$ is a *negative strain*, so that the last factor in each of the two values of P_0 is *numerically the sum*, not the difference, of the elastic limits (of tension and compression respectively) and the true stresses at the surface of the bore in the state of rest (circumferential and radial respectively).

The pressures in the state of rest may be computed directly from the shrinkages by the following formulas:

$$\left.\begin{aligned}(1)\quad \bar{P}_3&=E\,\frac{R_3^2-R_0^2}{2R_3^2}\cdot\frac{R_4^2-R_3^2}{R_4^2-R_0^2}\cdot\frac{S_3}{2R_3},\\ (2)\quad \bar{P}_2&=E\,\frac{R_2^2-R_0^2}{2R_2^2}\left(\frac{R_3^2-R_2^2}{R_3^2-R_0^2}\,\frac{S_2}{2R_2}+\frac{R_4^2-R_3^2}{R_4^2-R_0^2}\,\frac{S_3}{2R_3}\right),\\ (3)\quad \bar{P}_1&=E\,\frac{R_1^2-R_0^2}{2R_1^2}\left(\frac{R_2^2-R_1^2}{R_2^2-R_0^2}\,\frac{S_1}{2R_1}+\frac{R_3^2-R_2^2}{R_3^2-R_0^2}\,\frac{S_2}{2R_2}\right.\\ &\qquad\left.+\frac{R_4^2-R_3^2}{R_4^2-R_0^2}\,\frac{S_3}{2R_3}\right).\end{aligned}\right\}\qquad\text{(F)}$$

The terms in the parentheses are the values of the circumferential strains at R_0 caused by the assemblage of the successive layers, their sum with the negative sign being the total compressive strain at the surface of the bore as given by equation (D).

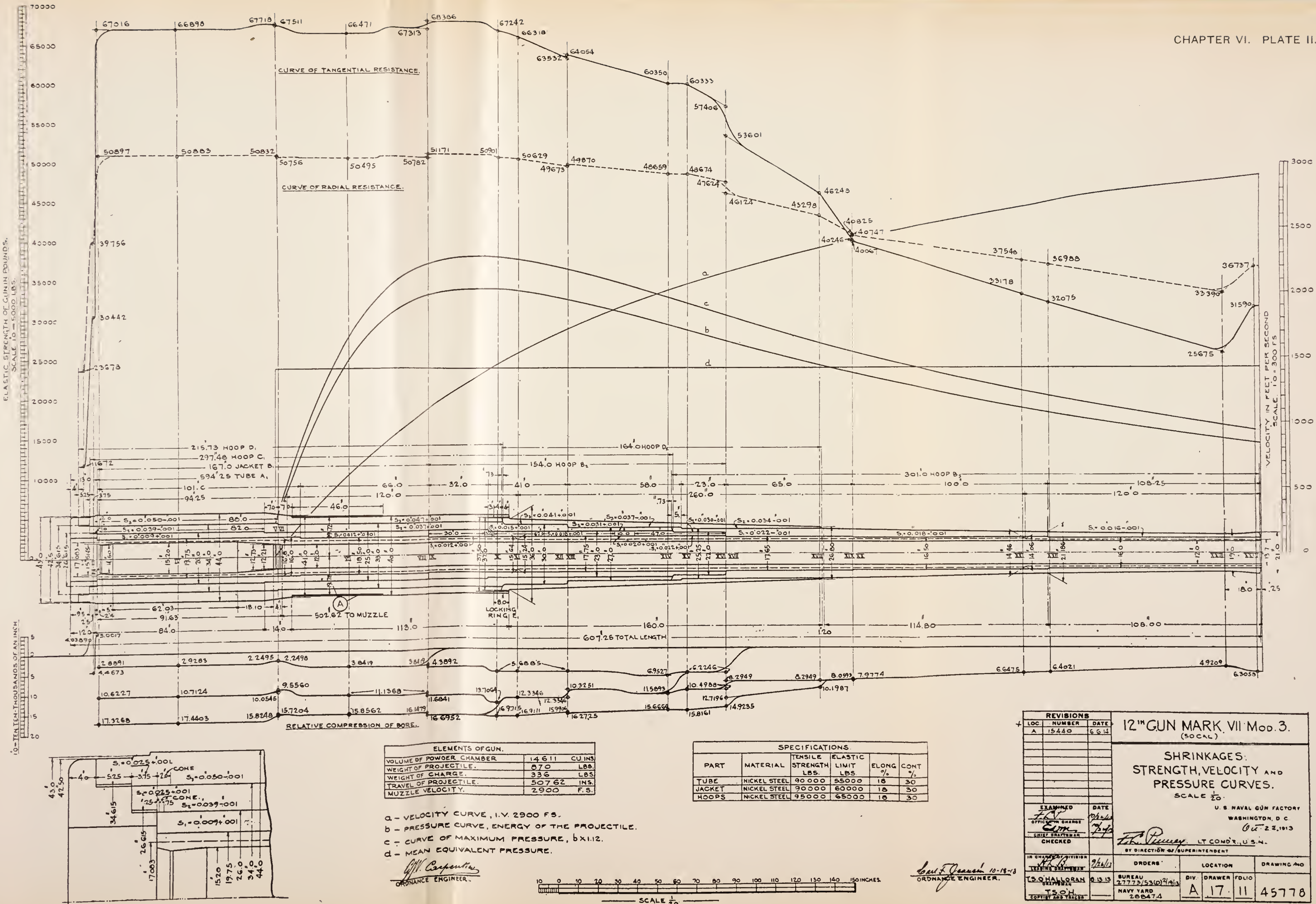
From the pressures in the state of rest, as given by (F), the pressures in the state of action may be found by equations (C), and the true circumferential tension of the inner surface of any layer can then be found by

$$Ee_t(R'_{n-1})=\frac{P_{n-1}(4R_n^2+2R_{n-1}^2)-6P_nR_n^2}{3(R_n^2-R_{n-1}^2)}.\qquad\text{(G)}$$

In this R_n and R_{n-1} are the outer and inner radii of any layer, P_n and P_{n-1} are the outer and inner pressures (either of action or of rest) and $Ee_t(R'_{n-1})$ is the true circumferential tension at the inner surface of the layer resulting from the action of P_n and P_{n-1}.

Similarly, the true radial compression at the inner surface of any layer, either in the state of rest or of action, is given by

$$Ee_\rho(R'_{n-1})=\frac{P_{n-1}(4R_n^2-2R_{n-1}^2)-2P_nR_n^2}{3(R_n^2-R_{n-1}^2)}.\qquad\text{(H)}$$



ELEMENTS OF GUN.		
VOLUME OF POWDER CHAMBER	14611	CU INS.
WEIGHT OF PROJECTILE.	870	LBS.
WEIGHT OF CHARGE.	336	LBS.
TRAVEL OF PROJECTILE.	507.62	INS.
MUZZLE VELOCITY.	2900	F. S.

SPECIFICATIONS.

PART	MATERIAL	TENSILE STRENGTH LBS.	ELASTIC LIMIT LBS.	ELONG %	CONT %
TUBE	NICKEL STEEL	90 000	55000	18	30
JACKET	NICKEL STEEL	90000	60000	18	30
HOOPS	NICKEL STEEL	95000	65000	18	30

a – VELOCITY CURVE, I.V. 2900 F.S.
b – PRESSURE CURVE, ENERGY OF THE PROJECTILE.
c – CURVE OF MAXIMUM PRESSURE, b×1.12.
d – MEAN EQUIVALENT PRESSURE.

CHAPTER VII.

GRAPHIC REPRESENTATION OF THE RELATION OF PRESSURES AND SHRINKAGES OF BUILT-UP GUNS FOR THE STATES OF ACTION AND REST.

256. Object of the diagram.—The object of this diagram is to show, graphically, how any one element of the strength of a gun, such as shrinkage, pressure in the bore, pressures at contact surfaces, in action and at rest, is related to every other element and how a modification of one element affects the others. It is an attempt to show, graphically, in principle, the coordinate relation of all conditions of the parts of the gun cylinders between the states of action and rest and the limiting conditions for both of these states.

257. One cylinder.—Strains.—With reference to gun construction, a simple cylinder under pressure may be overstrained in two directions, viz., (1) in the direction of a radius, (2) at right angles to the radius or circumferentially. These strains may be (1) a radial strain of compression, (2) a radial strain of extension, (3) a circumferential strain of compression, and (4) a circumferential strain of extension.

258. Pressures.—Radial and circumferential strains may be produced, (1) by a pressure P_0, inside the cylinder, tending to burst it, or, (2) by a pressure P_n, outside the cylinder, tending to collapse it, or, (3) by a combination of these two pressures acting at the same moment.

The equation numbers correspond with those in Chapter VI.

259. Internal pressure.—When an internal pressure acts alone, the value of the pressure which will just bring the material of the cylinder, at its inner surface, to its elastic limit of circumferential strain is

$$P_0(\theta) = \frac{3(R_n^2 - R_0^2)\theta}{4R_n^2 + 2R_0^2}, \tag{20}$$

and that pressure which will just bring the inner surface to its elastic limit of radial strain is

$$P_0(\rho) = \frac{3(R_n^2 - R_0^2)\rho}{4R_n^2 - 2R_0^2} \tag{22}$$

in which θ and ρ are the elastic limits of the material of the cylinder

under tension and compression, respectively, as determined in a testing machine.

Assume now two axes at right angles, on one of which is measured internal pressures, and on the other external pressures.

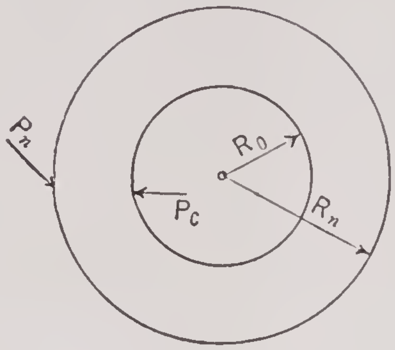


FIG. 39.

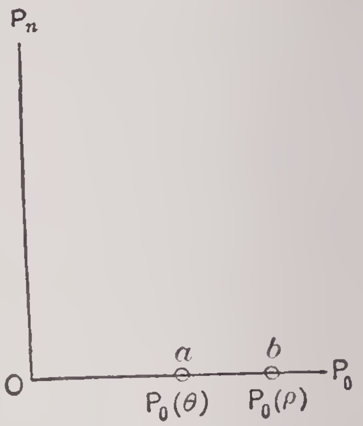


FIG. 40.

Plot on these the values of P_0 as determined by equations (20) and (22). In this case, as only internal pressure is acting, $P_n = 0$ and equation (20) will give a value of $P_0(\theta)$ equal, we will assume, to *Oa*, Fig. 40.

Before plotting the value of P_0 from equation (22) we must compare the value of θ and ρ. In the case of forged steel used in modern gun construction, these elastic limits are usually taken to be equal, but with some materials, notably cast iron, ρ is considerably greater than θ, and even in the case of steel it is probable that ρ is always somewhat greater than θ.

Remembering this, a comparison of the denominators of equations (20) and (22) shows that $P_0(\rho)$ for this case is greater than $P_0(\theta)$ and will plot at *b* some pressure *greater* than *Oa*.*

Recalling now the statement made in the earlier part of the text that in gun construction a cylinder must not under any circumstance be subjected to a pressure which will overstrain it circumferentially (see paragraph 228), a glance at Fig. 40 shows that as far as the utility of this one simple cylinder, as a gun complete in itself, is concerned the interior pressure due to the powder must not exceed $P_0(\theta) = Oa$, Fig. 40, and that all pressures between *a* and *b* overstrain the cylinder circumferentially, and are therefore unsafe.

* The only excuse for inserting a diagram of such simplicity in this text is to logically lead to the complete graphic representation of all equations.

The outside, or last exterior, cylinder of a built-up gun works under identically the same condition as we have here considered, and, in gun construction, its strength is determined by that value of the interior pressure which will just bring the inner surface to its limit of circumferential extension.

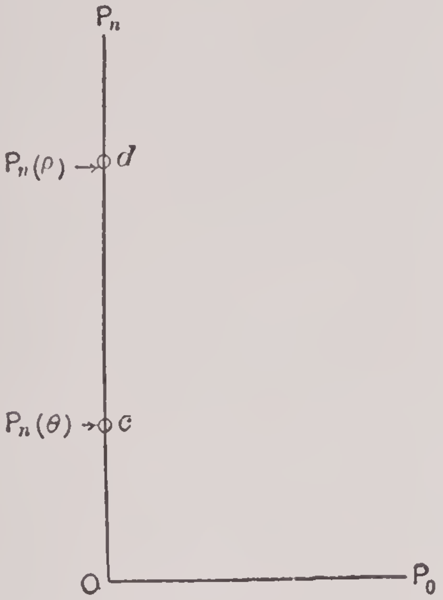


FIG. 41.

260. External pressure.—Consider now the same simple cylinder subjected only to an external pressure P_n.

The value of this pressure which will just bring the inner surface of the cylinder to its elastic limit of circumferential strain is

$$P_n(\theta)=\frac{(R_n^2-R_0^2)\rho}{2R_n^2} \tag{24}$$

and the value of the pressure which will just bring the inner surface of the cylinder to its elastic limit of radial strain is

$$Ec_p=-\frac{2P_nR_n^2}{3(R_n^2-R_0^2)}\left(1-\frac{2R_0^2}{r^2}\right) \tag{25}$$

in which $Ec_p=\rho$. This expression will be a maximum when $r=R_0$, whence

$$\rho=-\frac{2P_nR_n^2}{3(R_n^2-R_0^2)}(1-2),$$

or

$$P_n(\rho)=3\left[\frac{(R_n^2-R_0^2)\rho}{2R_n^2}\right] \text{ which we will call } (25a)$$

Plotting these values on a diagram similar to Fig. 40, we have, P_0 now being zero, Fig. 41.

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A comparison of (24) and (25a) shows $P_n(\rho)$ to be three times greater than $P_n(\theta)$, but, as it is not admitted, under any circumstances in gun construction, that we may allow our cylinders to be overstrained circumferentially, the strength of the cylinder for our purpose is given by the value of $P_n(\theta) = Oc$, Fig. 41.

This is the condition of the tube, or last interior cylinder, of a built-up gun in the state of rest in which the powder pressure ceases to act in the bore.

261. Both internal and external pressure acting on a single cylinder.—Consider now the case in which both internal and external pressures are acting together, and assume the case in which the internal pressure is greater than the external. This is the case when the powder pressure acts in the bore.

When P_0 is greater than P_n, the case we assume, there are two equations expressing the greatest allowable value of P_0. They are

$$P_0(\rho) = \frac{3(R_n^2 - R_0^2)\rho + 2P_nR_n^2}{4R_n^2 - 2R_0^2} \tag{27}$$

and

$$P_0(\theta) = \frac{3(R_n^2 - R_0^2)\theta + 6P_nR_n^2}{4R_n^2 + 2R_0^2}. \tag{28}$$

The first of these gives the value of that pressure inside the bore, P_0, which, acting with P_n, will bring the cylinder, at its inner surface, to its elastic limit of strain by radial compression; the second gives that value of P_0 which will bring the inner surface to its elastic limit of strain circumferentially. The least of these two values of P_0 is the true value of the maximum *allowable* internal pressure, but, since which of them will be the least depends upon the values of P_n, R_n, and R_0, both are expressed.

For a particular cylinder, *i. e.*, fixed values of θ, ρ, R_n, and R_0, these equations take the form

$$P_0(\rho) = B + CP_n \tag{27a}$$

and

$$P_0(\theta) = A + DP_n \tag{28a}$$

in which A, B, C, and D are constants depending upon the values of R_0, R_n, θ, and ρ. In modern gun construction θ is usually equal to ρ.

Equations (27a) and (28a) are equations of two straight lines which do not pass through the origin. These may now be plotted as shown in Fig. 42. Fig. 42 is the same as Fig. 36, Chapter VI, and it is this figure which is the basis of the final graphic solutions. The heavy lines given in Fig. 42 are plotted from equations (27a) and (28a). That marked $P_nP_0(\rho)$ is plotted from equation (27a), and, for any point on this line, its ordinate will give that value of P_n, and its abscissa that value of P_0, which, *acting together*, will just bring the inner surface of the cylinder to its elastic limit by radial compression. The line $P_nP_0(\theta)$ is plotted from equation (28a) and its ordinates and abscissæ give coincident values of P_n

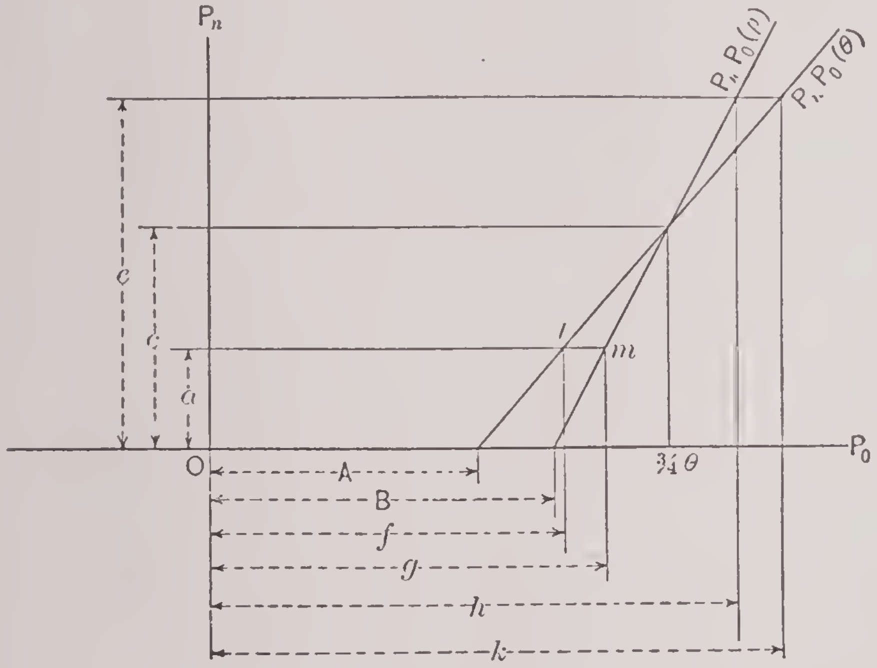

FIG. 42.

and P_0 which will just bring the inner surface of the cylinder to its elastic limit of strain by circumferential extension.

This diagram, at a glance, furnishes the following information:

If the external pressure on the cylinder be a tons per square inch, what values may P_0 have? From $P_n = a$, draw a horizontal line until it cuts the heavy lines at l and m. There are thus two values of P_0, one $P_0 = f$ tons acting with $P_n = a$ tons will bring the inner surface of the cylinder to its elastic limit by circumferential extension, and another $P_0 = g$ tons, which will bring the inner surface to its elastic limit of strain by radial compression.

Similarly, if $P_n = c$ tons per square inch, P_0 may have the value h, or k, tons. It is to be noted, for this value of P_n, that the inner surface of the cylinder will reach its elastic limit of radial strain before it reaches the elastic limit of strain by circumferential extension. In other words, for $P_n = c$, the horizontal line through $P_n = c$ cuts $P_nP_0(\rho)$ before it cuts the line $P_nP_0(\theta)$, the reverse of what happened at $P_n = a$.

When $P_0 = \frac{3}{4}\theta$ the lines cross, and at this point a value of $P_n = c$, acting with $P_0 = \frac{3}{4}\theta$, will bring the inner surface of the cylinder to its limits of radial and circumferential strain at the same instant.

When $P_n = 0$, P_0 has two values, A and B, and these values are those of equations (20) and (22) as plotted in Fig. 40.

This figure also shows how the existence of an external pressure increases the strength of the gun and allows greater powder pressures to be used in the bore, for when $P_n = 0$, $P_0 =$ either A or B, and when $P_n =$ any value greater than 0, P_0 becomes greater than A or B, *i. e.*, it allows a greater value of pressure in the bore before the cylinder at its inner surface is strained to its elastic limit radially or circumferentially.

262. How P_n is developed in gun construction.—Resting temporarily from consideration of Fig. 42, consider again the simple, single, cylinder as being at rest free from all pressure. Suppose there is slipped over the outside of the first cylinder another cylinder which just nicely fits the first cylinder while it is at rest free from all pressure. Let this second cylinder, the jacket, just touch every point at its surface of contact with the first cylinder, the tube, without exerting any pressure, both of them being in the free normal condition of the metal of which they are composed. Now let a pressure, P_0, be gradually developed inside the first cylinder, *i. e.*, inside the tube.

As this pressure arises the tube will expand, and as it expands it will be resisted in its attempt by the restraining influence of the jacket and a pressure thus set up at the surface of contact. There is thus produced an external pressure on the tube.

As P_0 increases the tube will tend to further expand, the jacket will further resist this expansion and there will be developed a further increase in pressure at the surface of contact of the jacket and tube.

Let R_0, R_1, and R_2 be the radii of the tube and jacket, respectively, θ and ρ the elastic strength of the tube material, and

let p_1 be the pressure at the surface of contact as developed by the action of P_0 in the interior of the tube, *i. e.*, in the bore.

The value of p_1 is given by the formula

$$p_1 = \frac{R_0^2(R_2^2 - R_1^2)}{R_1^2(R_2^2 - R_0^2)} \times p_0. \tag{34}$$

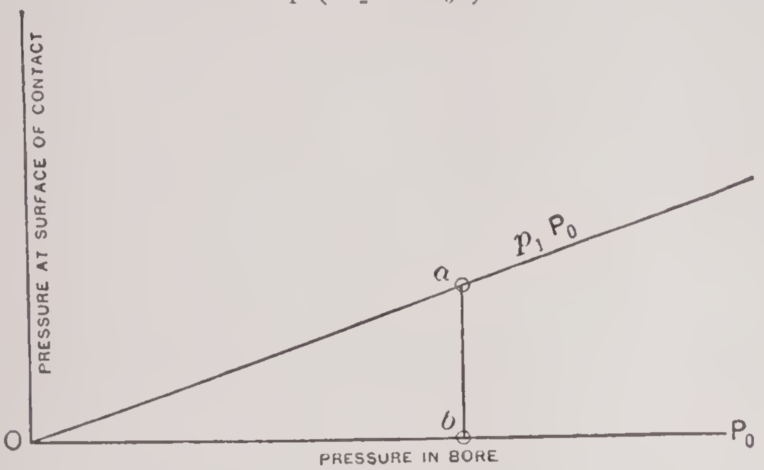

FIG. 43.

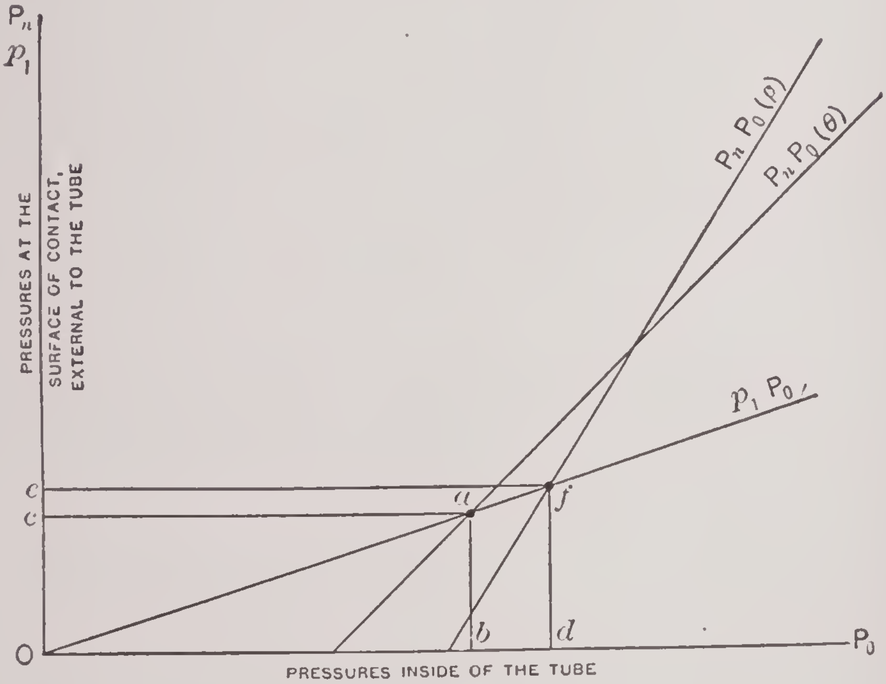

FIG. 44.

For our compound cylinder of definite radii, the pressure developed at the surface of contact (whose radius is R_1) is by (34) a fixed fraction of the internal pressure which develops it, and equation (34) may be plotted as a straight line, as shown in Fig. 43.

In Fig. 44 are combined Figs. 42 and 43, to consider the strength of the tube as affected by the pressure p_1 developed at the surface of contact of the tube and the jacket.

Before discussing Fig. 44, a comment must be made upon the notation used in Figs. 42 and 43. All lines are designated by the quantities by which they are plotted. Thus, p_1P_0, Fig. 43, is plotted with values of P_0 as abscissæ and coincident values of p_1 as ordinates. It is to be noted, too, that as far as the tube is concerned p_1 is a particular case of external pressure for the tube. P_n has been used to designated external pressures in general on the tube.

Consider now the line p_1P_0 in Fig. 44. When the pressure in the bore has reached a value $P_0=Ob$, the line p_1P_0 merely shows that the external pressure, p_1, at the contact surface, due to the restraining influence of the jacket, has reached a value $p_1=ba$. But, at a the line p_1P_0 cuts the line $P_nP_0(\theta)$. This last line is that for any point of which its coordinates represent a combination of internal and external pressure which will just bring the inner surface of the tube to its elastic limit of circumferential strain, so, the coordinates of the point in which the line p_1P_0 cuts $P_nP_0(\theta)$ will give that value of P_0 beyond which we cannot increase P_0 without overstraining the inner surface of the tube circumferentially, for which value of $P_0=Ob$, we have $P_n=p_1=ba$.

Similarly, where p_1P_0 cuts $P_nP_0(\rho)$ in f will give a value of $P_0=Od$ beyond which P_0 may not be increased without overstraining the tube radially.

As we cannot allow our cylinder as a gun tube to exceed the elastic limit of circumferential strain the strength of our compound cylinder gun, as limited by the tube, if everything else is favorable, is given by the value of $P_0=Ob$.

The next question is this: Are other conditions favorable and can we adopt this value of $P_0=Ob$ and, basing our powder charges on it, have the gun safe?

Further consideration of pressure developed at the surface of contact.—Limits imposed by the jacket.—We cannot answer the preceding question without further considering the pressure at the surface of contact. This pressure while an external one for the tube is an internal one for the jacket. The pressure on the exterior of the jacket is the atmosphere and is considered as zero.

We have, therefore, to consider the effect of p_1 as an internal pressure on the jacket.

As p_1 increases it may reach a value which will overstrain the jacket circumferentially before the bore is overstrained, in which case we may not exceed in the bore a value of P_0 which will just bring the inner surface of the jacket to its elastic limit of circumferential strain.

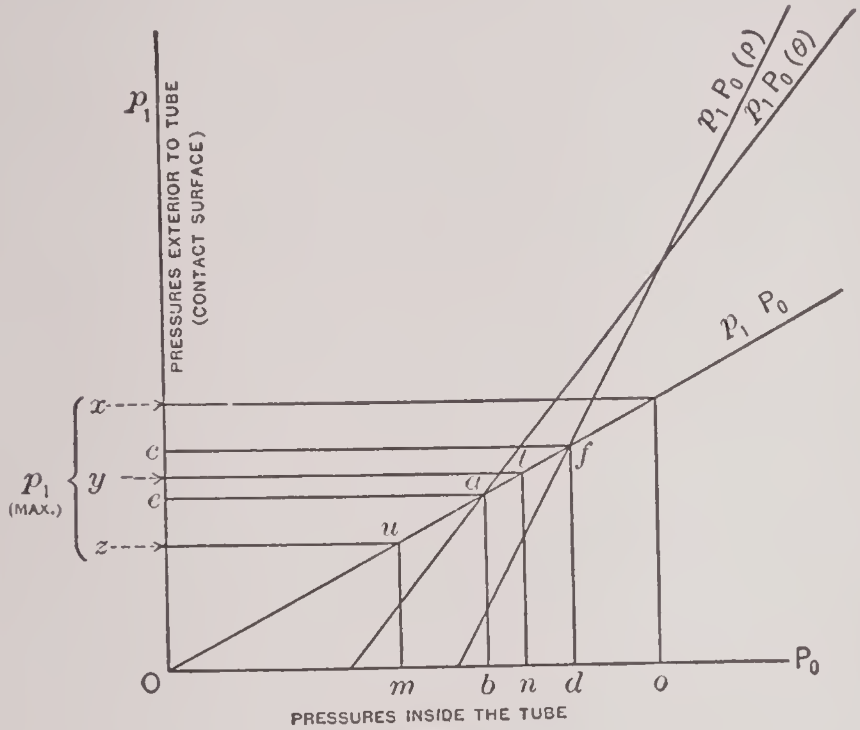

FIG. 45.

That value of p_1 which will just bring the inner surface of the jacket to its elastic limit of circumferential strain, which we designate by p_1 (max.) is, see equation (20),

$$p_1(\text{max.}) = \frac{3(R_2^2 - R_1^2)\theta_1}{4R_2^2 + 2R_1^2} \tag{20}$$

in which R_2 and R_1 are the radii of the jacket and θ_1 the elastic strength under tension of the material of which the jacket is made.

As this is the limiting value of the interior pressure of the jacket at the surface of contact, it is also the *practical* limit, for the gun, of the external pressure on the tube at the surface of contact and we can plot it on Fig. 44.

As it was desired to have Fig. 44 free from all lines not essential to the text up to that point, Fig. 44 is reproduced, as Fig. 45,

with a change essential to consistency in notation. The P_n of the original simple cylinder was a general symbol expressing an external pressure on the tube. We have used p_1 to designate the external pressure arising from placing the jacket on the tube and as this is so far the only external pressure considered as acting the symbol p_1 is substituted for P_n, as shown in Fig. 45.

Fig. 45 gives the following information: If the strength of the jacket limits the value of p_1 (max.) to Oz, then P_0 cannot exceed a value $P_0 = om$ without overstraining the *jacket*, since by the line p_1P_0 when $P_0 = om$, $p_1 = um = Oz$ and any further increase of P_0 will make $p_1 > Oz$, although the tube will not, at its inner surface, be overstrained circumferentially until $P_0 = Ob$, or radially until $P_0 = od$, as determined by the intersection of p_1P_0 with $p_1P_0(\rho)$ and $p_1P_0(\theta)$.

Again, if p_1 (max.) as limited by the material of the jacket must not exceed Oy, then P_0 may have a value On without overstraining the jacket. But, by referring to the intersection of p_1P_0 with $p_1P_0(\theta)$ at a we see that P_0 must not be allowed to exceed $P_0 = Ob$ or the tube will be subjected to a pressure greater than that which will overstrain the bore circumferentially. We thus see there is for the condition we have just discussed a margin of safety in the jacket, as it will allow us to strain the tube to its elastic limit circumferentially by a value of $P_0 = Ob$ without being brought to its own limit of strain.

Again, we cannot carry P_0 to the value Od, which would bring the tube to its limit of radial strain, for in so doing p_1 would rise from a to f, and would cause $p_1 = fd = oc > Oy$, therefore Oy is the limit of p_1 allowed by the jacket and must not be exceeded.

Again, if the jacket permits a value of p_1 (max.) $= Ox$ to be safely withstood by itself there would be required, by running from x to the line p_1P_0 and down to o a value of $P_0 = Oo$ tons to develop this value of p_1. A glance at the diagram, Fig. 45, will show that the combination of $P_0 = Oo$ and $p_1 = Ox$ is much in excess of the conditions represented at a and f, at which points the tube is at its limit of circumferential and radial strains. In consequence, the extra strength of the jacket which enables it to stand an internal pressure p_1 (max.) $= Ox$ is useless since the tube is not strong enough to stand a value of P_0 which will produce p_1 (max.) $= ox$.

263. Two cylinders assembled with shrinkage.—Let us return now to the consideration of our original simple cylinder, taking it up at the point at which we were about to slip the jacket on it. Assume, also, that the jacket was too small to slip over the tube, and that we are compelled to heat it, causing it to expand sufficiently to allow it to be slipped over the tube, and that from this condition, while in place on the tube, it is allowed to cool.

As it cools it will attempt to contract, or shrink, and return to its original diameter. This effort to shrink will be resisted by the tube and a pressure will be set up at the surface of contact, which will increase with the further tendency of the jacket to cool, until the jacket and the tube have reached the normal temperature of the air. This pressure will then become stationary. We will designate it by $\bar{P}_1$.

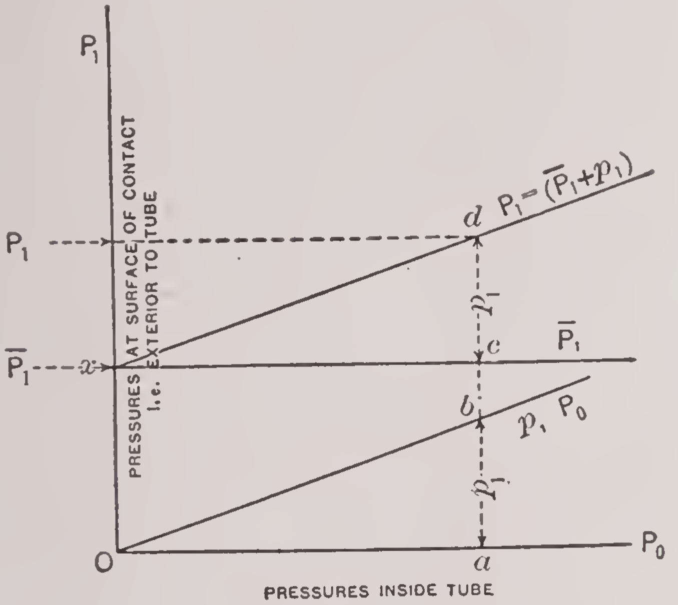

FIG. 46.

264. Effect of pressure due to shrinkage plus pressure developed at contact surface by the pressure in the bore.—When this compound cylinder has cooled and is in equilibrium, the only pressure in existence is $\bar{P}_1$ and it is necessary to investigate the effect of this, when additional pressure p_1 at the contact surface, due to P_0 in the bore, is brought into existence.

When P_0 acts, the pressure now at the contact surface is $\bar{P}_1 + p_1$. The sum of $\bar{P}_1 + p_1$ we shall denote by P_1, it being the resultant pressure at the contact surface, due to shrinking on the jacket, and to the existence of a pressure in the bore.

In Fig. 46 plat the line p_1P_0, which shows the values of the pressure at the contact surface due to P_0, and on the same axes draw a line representing $\bar{P}_1$ as produced by the amount of shrinkage (S_1) with which the cylinders have been assembled.

Now when P_0 has reached a value Oa, Fig. 46, p_1 has the value ab, and the total pressure at the surface of contact, P_1, is $(\bar{P}_1+p_1)=ac+ab=ad=P_1$.

It is evident that we may obtain instantly the value of P_1 for any value of P_0 by simply drawing through x a line parallel to the line p_1P_0 and, that this line, for any given value of $\bar{P}_1$, will give coincident values of the total pressure at the surface of contact and pressures in the bore.

This diagram has another property, as follows: If the point d, Fig. 46, represents a condition due to certain coincident values of P_1 and P_0, and a line be drawn through d parallel to the line p_1P_0, the point at which that line cuts the vertical axis OP_1 will give ox, which is that value of $\bar{P}_1$ which we must have in order to produce the coincident values of P_1 and P_0 represented by d.

For example, if the coordinates of d, Fig. 46, were the values of P_1 and P_0 which would just bring the inner surface of the tube to its elastic limit of circumferential strain, and we draw a line through d parallel to p_1P_0 we can find what value of $\bar{P}_1$ will be necessary in order to have the inner surface of the tube reach its elastic limit of circumferential strain under a pressure of $P_0=Oa$ tons in the bore.

This knowledge is important because it will enable us directly and graphically to show what influence the *amount* of shrinkage has, and what amount is necessary to produce the desired value of $\bar{P}_1$.

265. Shrinkage and $\bar{P}_1$.—By shrinkage, is meant the difference, at the surfaces of contact, of the diameters of the jacket and tube before they are assembled.

The pressure $\bar{P}_1$ produced, at the surface of contact, by shrinking on the jacket is.

$$\bar{P}_1=\frac{E(R_1^2-R_0^2)(R_2^2-R_1^2)}{2R_1^2(R_2^2-R_0^2)}\times\frac{S_1}{2R_1} \qquad (37)$$

in which $\frac{S_1}{2R_1}$ is substituted for ϕ_1 (see paragraph 222).

For definite values of R_2, R_1, and R_0 the equation may be plotted as a straight line $\bar{P}_1S_1$ and combined with Fig. 46, as shown in Fig. 47.

This diagram gives the following information: What shrinkage is necessary to produce at the surface of contact a pressure $P_1=Ou$ tons, when $P_0=Od$ tons, and what is the pressure due to this shrinkage when the gun is in a state of rest, *i. e.*, when the powder pressure has disappeared from the bore?

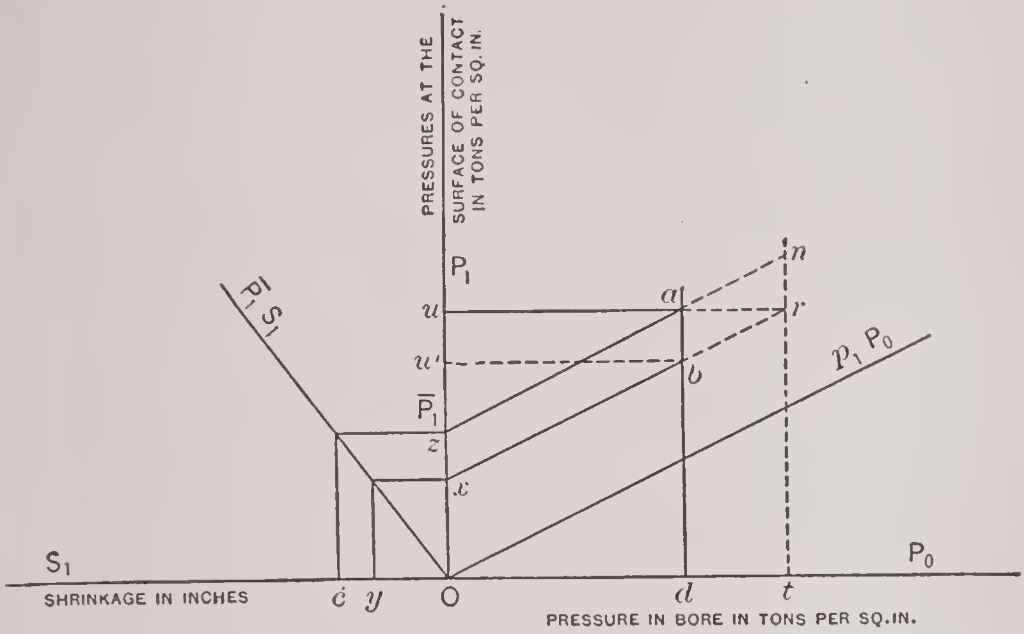

FIG. 47.

Solution.—At u, for $P_1=Ou$ draw ua. At d, for $P_0=Od$, erect a perpendicular cutting ua in the point a. Through a, draw a line parallel to p_1P_0 to z. Then $\bar{P}_1=Oz$. Continuing from z, parallel to the horizontal axis to the line $\bar{P}_1S_1$ and then drop to c. Oc is the shrinkage desired, and Oz is its corresponding pressure in the state of rest.

If for any reason we wish to maintain P_0 at its value Od tons but, because of the jacket cannot allow P_1 to exceed the value bd tons, what must be the value of P_1 and what shrinkage (S_1) must be used to accomplish this?

Solution.—From b draw a line parallel to p_1P_0, cutting the vertical axis at x. Then $\bar{P}_1=Ox$ and its corresponding shrinkage is $S_1=Oy$.

With a given shrinkage Oc and a maximum allowable value of $P_1 = Ou$, what is the maximum allowable value of P_0?

Solution.—From c, for $S_1 = Oc$, go to $\overline{P}_1S$ and then over to z. Through z, draw a line parallel to p_1P_0 until it cuts the horizontal line through $u(P_1 = Ou)$ at the point a; drop to d. The maximum allowable value of P_0 is then $P_0 = Od$.

What is the effect on the pressure at rest $(\overline{P}_1)$ if in assigning a shrinkage we adopt $S_1 = Oy$ instead of $S_1 = Oc$?

Solution.—From c and y, run up to $\overline{P}_1S_1$ and over to z and x. $\overline{P}_1$ will be reduced from Oz to Ox tons.

In the preceding case, if P_1 is to be kept constant at $P_1 = Ou$, how must the pressure in the bore be varied since the shrinkage has been reduced?

Solution.—Through u draw $P_1 = Ou$. Through x (the value of $\overline{P}_1$ corresponding to the reduced value of the shrinkage) draw a line parallel to p_1P_0 until it cuts $P_1 = Ou$ in the point r. From r drop to t. Therefore, with the reduced shrinkage P_0 must be increased from Od to Ot tons if P_1 is to remain constant, *i. e.*, if the jacket is to be worked to its limit.

If the final pressure at rest, *i. e.*, the pressure $\overline{P}_1$, due to the shrinkage, be too great the tube may collapse through the effect of $\overline{P}_1$ acting alone after the powder pressure, P_0, has left the bore and no longer supports the tube.

Now take the following conditions for a problem: (1) P_0 must not exceed Od tons or the tube will be overstrained circumferentially while the powder pressure acts. (2) The pressure in action at the surface of contact, P_1, must not exceed the value $P_1 = Ou$ or the jacket will be overstrained circumferentially during the existence of the powder pressure in the bore. (3) The value of $\overline{P}_1$ must not exceed Ox or the tube will collapse when the powder pressure ceases to act and support the bore.

Under these conditions, what shrinkage may be used, and will the jacket be overstrained, or not, when the tube is just brought to its elastic limit of circumferential strain?

Solution.—At $P_0=Od$ erect a perpendicular and through x draw a line parallel to p_1P_0 intersecting the perpendicular from d in the point b. Draw bu'. Then $P_1=Ou'<P_1=Ou$ and the jacket is not overstrained. The shrinkage corresponding to $\bar{P}_1=Ox$ is $S_1=Oy$.

Assume the following conditions for a problem: (1) The jacket will be brought to its limit of circumferential strain by a pressure $P_1=Ou$. (2) The tube will be brought to its limit of circumferential strain by a pressure $P_0=Ot$. (3) The tube at rest, *i. e.*, when not supported by a powder pressure in the bore, cannot safely stand a pressure greater than $\bar{P}_1=Oz$.

Problem.—Under these conditions, find what shrinkage must be used to bring the tube and jacket simultaneously to their elastic limits of circumferential strain, what final pressure at rest will be produced, and whether or not the tube can stand this pressure when the gun is at rest.

Solution.—Draw $P_1=Ou$ and $P_0=Ot$ intersecting in r. Through r draw rx parallel to p_1P_0. The tube will be safe at rest because $Ox<Oz$. The shrinkage corresponding to $P_1=Ox$ is $S_1=Oy$.

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266. Formulas for a gun of two cylinders.—The formulas which follow are those for a gun consisting of a compound cylinder composed of two elementary cylinders assembled with shrinkage:

$$\left.\begin{aligned}
&\text{(a)} \quad P_1(\text{max.}) = \frac{3(R_2^2-R_1^2)\theta_1}{4R_2^2+2R_1^2},\\
&\text{(b)} \quad P_0(\theta) = \frac{3(R_1^2-R_0^2)\theta_0+6P_1R_1^2}{4R_1^2+2R_0^2},\\
&\text{(c)} \quad P_0(\rho) = \frac{3(R_1^2-R_0^2)\rho_0+2P_1R_1^2}{4R_1^2-2R_0^2},\\
&\text{(d)} \quad P_1(\text{max.}) = \frac{(R_1^2-R_0^2)\rho_0}{2R_1^2}\\
&\text{(e)} \quad p_1 = \frac{R_0^2(R_2^2-R_1^2)P_0}{R_1^2(R_2^2-R_0^2)},\\
&\text{(f)*} \quad S_1 = \frac{4R_1^3(R_2^2-R_0^2)\bar{P}_1}{E(R_1^2-R_0^2)(R_2^2-R_1^2)}.
\end{aligned}\right\} \quad (36)$$

* Derived from formula (37) Elastic Strength of Guns.

P_1(max.) = That pressure at the surface of contact which, if exceeded, will overstrain the jacket circumferentially.

P_1 = The sum of all pressures at the surface of contact during the existence of a pressure P_0 in the bore, *i. e.*, while the gun is at the instant of firing. It is the sum of $\bar{P}_1$ and p_1.

p_1 = That portion of the total pressure at the surface of contact which is developed at that surface by the existence of P_0 in the bore.

$\bar{P}_1$ = The pressure at the contact surface produced by shrinking on the jacket. When the gun is not in the act of firing $P_0 = O$, and $\bar{P}_1$ is the only pressure, an external one to the tube. If great enough it will overstrain the tube and tend to collapse it when P_0 ceases to act.

$\bar{P}_1$(max.) = That value of $\bar{P}_1$ which cannot be exceeded without overstraining the inner surface of the tube when P_0 ceases to act.

S_1 = The shrinkage producing $\bar{P}_1$.

P_0 = Any pressure in the bore. It may be $P_0(\theta)$ or $P_0(\rho)$ in value.

$P_0(\theta)$ = That pressure in the bore which combined with P_1 at the surface of contact will just bring the inner surface of the tube to its elastic limit of circumferential strain.

$P_0(\rho)$ = That pressure in the bore which combined with P_1 at the surface of contact will just bring the inner surface of the tube to its elastic limit of radial strain.

$\theta_0 = \rho_0$ = Elastic strength of material of tube for extension and compression.

$\theta_1 = \rho_1$ = Same for the jacket.

267. **Computed diagram for two cylinders.**—A complete diagram for a case of two cylinders is given in Fig. 48.

The data for this is taken from Art. 224:

$R_0 = 3''$, $R_1 = 5''$, $R_2 = 8''$, $\theta_0 = \rho_0 = 18$ tons per sq. in., $\theta_1 = \rho_1 = 24$ tons per sq. in.

For use in plotting Fig. 48, the equations (36) become:

$$P_1(\text{max.}) = 9.18 \text{ tons},$$
$$P_0(\theta) = 7.31 + 1.272P_1,$$
$$P_0(\rho) = 10.53 + 0.609P_1,$$
$$\bar{P}_1(\text{max.}) = 5.76,$$
$$p_1 = 0.2554P_0,$$
$$\bar{P}_1 = 295S_1.$$

268. Discussion of Fig. 48.—Use of $P_0(\theta)$ and $P_0(\rho)$.—From the formula $P_1(\text{max.})$ the jacket cannot stand a greater pressure at the surface of contact than $P_1(\text{max.}) = 9.18$ tons, with which value of P_1 a pressure $P_0 = 16.13$ tons will bring the tube to its elastic limit of radial strain, *i. e.*, $P_0(\rho) = 16.13$ tons; and, a pressure of $P_0 = 18.99$ tons will bring the inner surface of the tube to its elastic limit of circumferential strain, *i. e.*, $P_0(\theta) = 18.99$.

When $P_1(\text{max.}) = 9.18$ and $P_0(\rho) = 16.13$, $\bar{P}_1$ will have the value 5.06 tons which is less than $\bar{P}_1(\text{max.}) = 5.76$. The tube, therefore, will be safe at rest and the shrinkage which will just bring the jacket to its elastic limit of circumferential strain at the same time the tube reaches its elastic limit of radial strain, will be (for $\bar{P}_1 = 5.06$) $S_1 = .01715''$.

If with this shrinkage we increase P_0 from 16.13 to 18.99, P_1 will rise above the value 9.18, to c, Fig. 48, and the jacket will be overstrained.

What shrinkage, now, will enable the jacket and the tube to be brought simultaneously to their elastic limits of circumferential strain? From $d(P_1 = P_1(\text{max.}) = 9.18,\ P_0 = P_0(\theta) = 18.99)$ draw a line parallel to p_1P_0. This gives $\bar{P}_1 = 4.33$ and $S_1 = .01468$. The shrinkage is reduced and the pressure in the state of rest, $\bar{P}_1$, is also reduced from 5.06 to 4.33 tons.

As it is desirable to have as small pressures at rest as is consistent with developing the greatest possible strength of the gun, let us see what will be the effect of regulating the shrinkages by using $P_0(\theta)$ and using $P_0(\rho)$ for the limit beyond which we may not carry the pressure in the bore.

Refer to Fig. 48. Starting now from $\bar{P}_1 = 4.33$ ($S_1 = .01468''$ corresponding to $P_0(\theta) = 18.99$) the line of P_1 rises to $b = 8.45$ tons when $P_0(\rho) = 16.13$ tons. According to our diagram this line cuts the $P_1P_0(\rho)$ line at a, and if we proceed to b will slightly overstrain

the tube's inner surface by radial compression if with $P_1=4.33$ we carry the pressure in the bore to the value of 16.13 tons.

It is usually considered that this may be done with safety since the value of ρ_0 used in the formula is the value given by a free test of the specimen and not from a test of a specimen supported as by a jacket.

The practice in the Army and Navy is, when $P_0(\theta)>P_0(\rho)$ calculate shrinkages with it but limit powder pressures by $P_0(\rho)$. If $P_0\theta<P_0(\rho)$, then $P(\theta)$ must be used to determine both shrinkage and powder pressure. (See Art. 228.)

Referring again to Fig. 48, and considering it without reference to the immediately preceding remarks, we see that our tube in the state of rest will stand a maximum pressure from shrinkage of $\bar{P}_1(\text{max.})=5.76$ tons.

What will be the effect of adopting this shrinkage? The diagram shows that if we start with $\bar{P}_1=5.76$ its maximum allowable value, P_1 will reach its limiting value of 9.18 tons when $P_0=13.25$ tons. In other words, by adopting this shrinkage the jacket will be overstrained long before the tube, and the full strength of the compound cylinders cannot be utilized in firing, while the tube in the state of rest will be subjected to the maximum pressure due to shrinkage that it can stand without being overstrained.

The diagram thus shows at a glance the effect of adopting any shrinkage intermediate to those commented upon in this text, or the effect of the variation of any element for the state of action or rest, and the limiting value of the element considered for these states. The diagram is easily applied to the case of three cylinders.

269. The diagram for three cylinders.—Before explaining the construction of the diagram for the case of three cylinders it is necessary to discuss the effect of superimposing the third cylinder upon the two already assembled.

In the state of rest our compound cylinder composed of two simple cylinders assembled with shrinkage is subjected to but one pressure $\bar{P}_1$ existing at the surface of contact due to the shrinkage S_1 see (Fig. 49).

In the state of action there exists P_0 in the bore, its resultant p_1 at the contact surface in addition to $\bar{P}_1$ already existing at that surface (see Fig. 50).

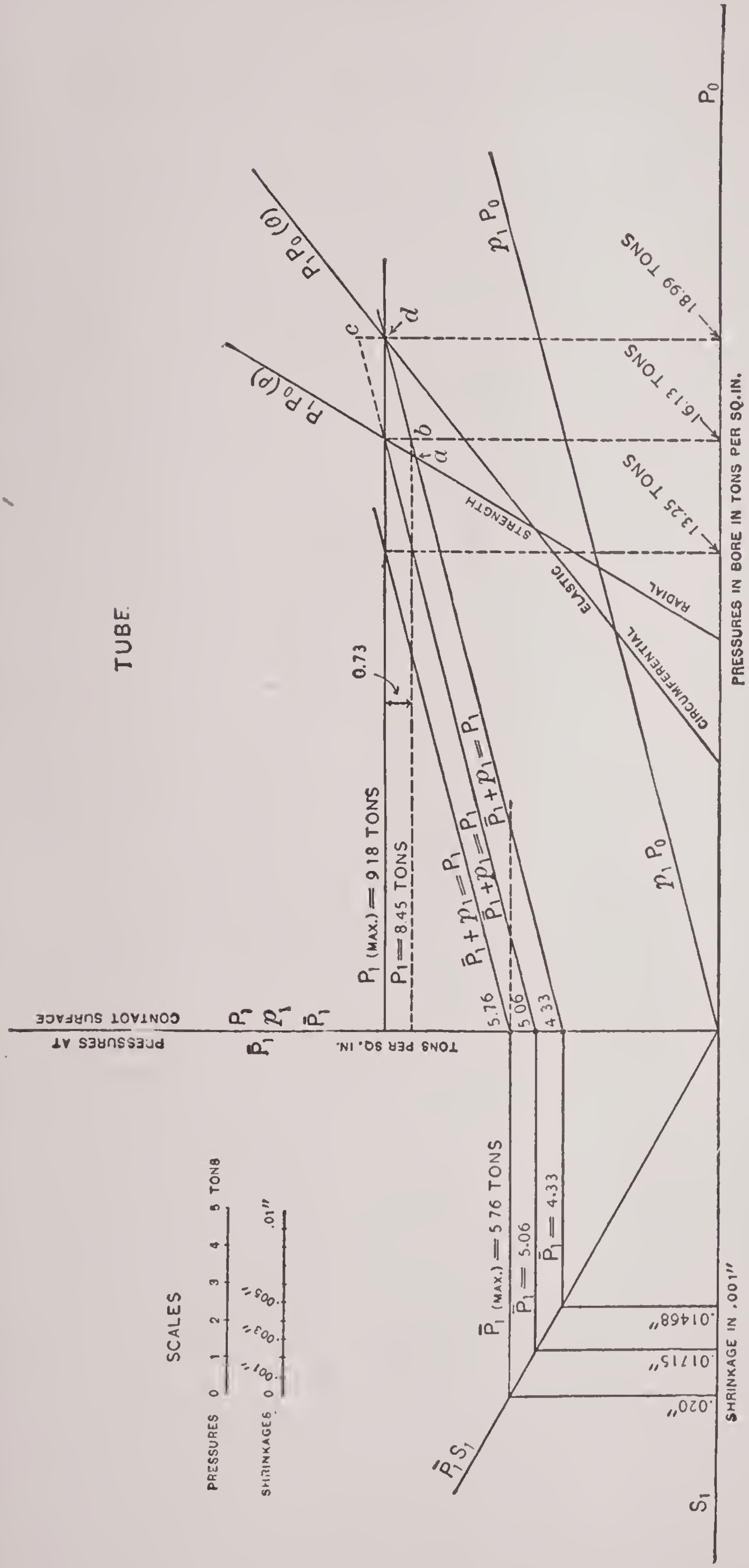

TUBE
SCALES
PRESSURES 0 1 2 3 4 5 TONS
SHRINKAGES 0 .001" .003" .005" .01"
PRESSURES AT CONTACT SURFACE
TONS PER SQ. IN.
PRESSURES IN BORE IN TONS PER SQ.IN.
SHRINKAGE IN .001"
18.99 TONS
16.13 TONS
13.25 TONS
RADIAL
ELASTIC STRENGTH
CIRCUMFERENTIAL
P_1 (MAX.) = 9.18 TONS
P_1 = 8.45 TONS
0.73
$\bar{P}_1$ (MAX.) = 5.76 TONS
P_1 = 5.06
$\bar{P}_1$ = 4.33
5.76
5.06
4.33
.020"
.01715"
.01468"
$\bar{P}_1 + p_1 = P_1$
$\bar{P}_1 + p_1 = P_1$
$\bar{P}_1 + p_1 = P_1$
$p_1 P_0$
$\bar{P}_1 S_1$
P_0
S_1
a
b
c
d

Fig. 48.

Now take the compound cylinder in the state represented by Fig. 49 and shrink on it a third cylinder, termed a hoop, with a shrinkage of S_2 inches.

The surface at which this third cylinder clasps the jacket is called the second contact surface and the pressure at this surface

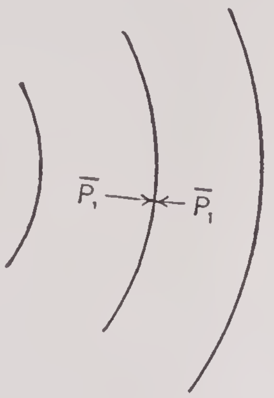


FIG. 49.

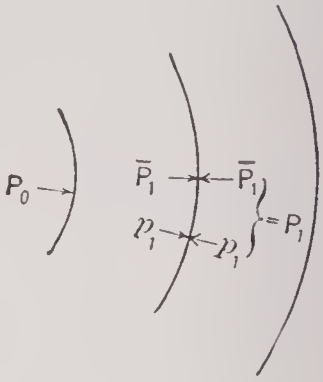


FIG. 50.

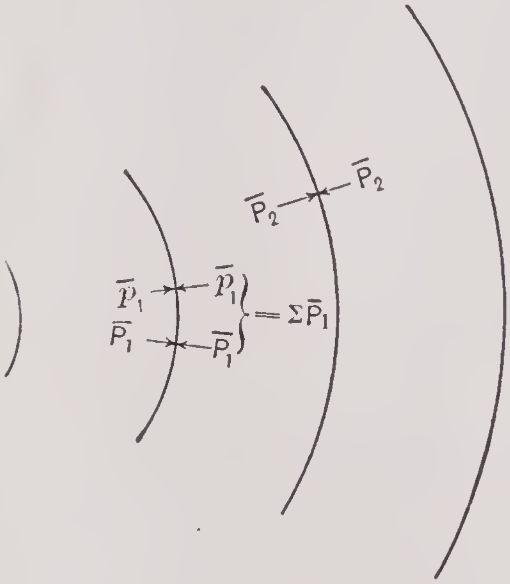


FIG. 51.

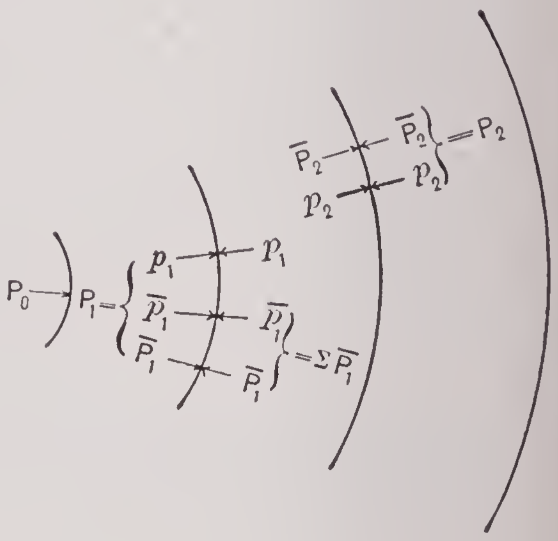


FIG. 52.

due to the shrinkage S_2 with which it is assembled we will designate by $\bar{P}_2$. $\bar{P}_2$ is in every respect similar to P_1 as discussed in the case of two cylinders, and is governed by the same laws.

In future, a quantity referring to pressures or shrinkages at the second contact surface are denoted by the subscript $_2$, and those for the first contact surface by the subscript $_1$.

When $\bar{P}_2$ is brought into existence by shrinking the hoop on the already assembled jacket and tube, a pressure due to $\bar{P}_2$ is transmitted through the jacket from the second to the first contact surface. This fraction of $\bar{P}_2$, designated by $\bar{p}_1$, will exist at the first contact surface in addition and coincident with the pressure, $\bar{P}_1$, already there due to shrinking the jacket on the tube.

The three cylinders assembled with shrinkage will, in the state of rest, be subjected to pressures as indicated in Fig. 51.

Starting with the conditions of Fig. 51, let a powder pressure P_0 be developed in the bore. P_0 produces at the first contact surface a pressure we will designate by p_1 and p_1 produces at the second contact surface a pressure p_2, both p_1 and p_2 existing at their respective contact surfaces in addition to the pressures already there due to the shrinkages.

The complete set of pressures for the three cylinders in the state of action is indicated in Fig. 52.

270. Notation of formulas for three cylinders.—

E	Modulus of elasticity.
R_0, R_1, R_2, R_3 . .	Radii of surfaces of cylinders.
$\theta_0, \theta_1, \theta_2$	Elastic limits of metal of tube, hoop, and jacket under tension.
ρ_0, ρ_1, ρ_2	Elastic limits of same under compression.
P_0, P_1, P_2 . . .	Total pressures; in the bore P_0; at the first contact surface, P_1; and at the second contact surface, P_2, with the system *in action*. Their maximum values which can be supported without exceeding the elastic limits, to be designated by the suffix (θ) or (ρ) accordingly as they represent pressures producing circumferential or radial strains.
$\bar{P}_1, \bar{P}_2$	Pressures, $\bar{P}_1$ at first contact surface due to shrinking jacket on tube; and, $\bar{P}_2$ at second contact surface due to shrinking hoop on jacket.
$\bar{p}_1$	Pressure at first contact surface due to $\bar{P}_2$ at second contact surface.
$\Sigma\bar{P}_1$	Sum of all pressures, for the state of rest, at the first contact surface.

$$\Sigma\bar{P}_1 = \bar{P}_1 + \bar{p}_1.$$

p_1 . . . . With the system in action, p_1 is the pressure at first contact surface due to P_0 in bore.

p_2 . . . . With the system in action, p_2 is the pressure at second contact surface due to p_1 at the first contact surface.

S_1, S_2 . . . . Shrinkages, in inches, producing $\bar{P}_1$ and P_2.

P_1(max.), P_2(max.) Values of P_1 and P_2 which cannot be exceeded without overstraining the jacket (P_1 max.), or hoop (P_2 max.), hence the limiting values of P_1 and P_2 for the state of action.

ΣP_1(max.) . . . That value of ΣP_1 which cannot be exceeded without overstraining the tube by compression of the bore when the tube is not supported by powder pressure, hence the limiting value of $\Sigma \bar{P}_1$ for the state of rest.*

* $\Sigma \bar{P}_1$ in this chapter is that designated by $\bar{P}_1$ in Chapter VI. The symbol $\Sigma \bar{P}_1$ is used here because it is desired to indicate that the total pressure at the first contact surface is composed of two elements due to separate shrinkages.

*FORMULAS FOR THREE CYLINDERS ASSEMBLED WITH SHRINKAGE.

I.	II.	III.	IV.	V.
Part affected.	Character of pressure.	Formula.	Plots the line.	Relationship shown by the line of col. IV.
HOOP.	Internal.	$P_2(\theta)=\dfrac{3(R_3^2-R_2^2)\theta_2}{4R_3^2+2R_2^2}$ (a)	P_2(max)	Value above which P_2 cannot rise without overstraining the hoop circumferentially.
JACKET.	External.	P_2	....	General symbol for pressure external to jacket.
		$\overline{P}_2=\dfrac{E(R_2^2-R_0^2)(R_3^2-R_2^2)}{4R_2^3(R_3^2-R_0^2)}\cdot S_2$ (b)	$\overline{P}_2S_2$	Shows the pressure produced at second contact surface by assembling the hoop with any shrinkage S_2.
		$p_2=\dfrac{R_1^2(R_3^2-R_2^2)}{R_2^2(R_3^2-R_1^2)}\cdot p_1$ (c)	p_2p_1	Shows the pressure produced at the second contact surface (in addition to that already existing there due to shrinking on hoop), by any pressure p_1 acting at the interior surface of the jacket. The line p_2p_1 is identical in character for the jacket with the line p_1P_0 for the tube. See Figs. 43, 44 and 46 and discussion thereupon, all of which applies in principle to the line p_2P_1.
	Internal.	$P_1(\theta)=\dfrac{3(R_2^2-R_1^2)\theta_1+6R_2^2P_2}{4R_2^2+2R_1^2}$ (d)	$P_2P_1(\theta)$	The coordinates of any point on this line show what coincident values of an external pressure P_2 with an internal pressure P_1 will just bring the inner surface of the jacket to its elastic limit of circumferential strain.
		$P_1(\rho)=\dfrac{3(R_2^2-R_1^2)\rho_1+2R_2^2P_2}{4R_2^2-2R_1^2}$ (e)	$P_2P_1(\rho)$	Similar to the above for the elastic limit of radial strain,

*Taken principally from Chapter VI, but also from Notes on the Construction of Ordnance Nos. 35 and 59, by Major Birnie, U. S. A. The gun is considered as a compound cylinder with free ends.

FORMULAS FOR THREE CYLINDERS ASSEMBLED WITH SHRINKAGE.—Continued.

I.	II.	III.	IV.	V.
Part affected.	Character of pressure.	Formula.	Plots the line.	Relationship shown by the line of col. IV.
JACKET, Cont'd.	Internal, Cont'd.	$\bar{P}_1 = \frac{E(R_1^2-R_0^2)(R_2^2-R_1^2)S_1}{4R_1^3(R_2^2-R_1^2)}$ (f)	$\bar{P}_1S_1$	Shows the pressure produced at the first contact surface by assembling the jacket with any shrinkage S_1. This pressure $\bar{P}_1$ (in these notes) does not include that pressure at first contact surface produced by shrinking on the hoop. $\bar{P}_1$ refers to the jacket alone and exists simultaneously with but distinct from $\bar{p}_1$.
		$\bar{p}_1 = \frac{R_2^2(R_1^2-R_0^2)}{R_1^2(R_2^2-R_0^2)} \cdot \bar{P}_2$ (g)	$\bar{p}_1\bar{P}_2$	Indicates what fraction of $\bar{P}_2$ is included, at first contact surface, in the value of $\Sigma\bar{P}_1$. It gives the element of pressure at the first contact surface due to $\bar{P}_2$ at the second surface. It is used to graphically separate $\Sigma\bar{P}_1$ into $\bar{p}_1$ and $\bar{P}_1$.
		$p_1 = \frac{R_0^2(R_3^2-R_1^2)}{R_1^2(R_3^2-R_0^2)} \cdot P_0$ (h)	p_1P_0	Shows the pressure produced at the first contact surface by P_0 in the bore. This pressure, p_1, is in addition to any pressure due to shrinkages already existing at the first contact surface. See Figs. 43, 44 and 46 and discussion thereto.
TUBE.	External.	P_1 (i)	....	General symbol for total pressure at first contact surface for the state of action. It is therefore the sum of $p_1+\bar{p}_1+\bar{P}_1$ at any instant.
		$\bar{P}_1$ (j)	$\bar{P}_1S_1$	Same as (f) for jacket. It is an internal pressure for the jacket but external to tube.

FORMULAS FOR THREE CYLINDERS ASSEMBLED WITH SHRINKAGE.—Continued.

I.	II.	III.	IV.	V.
Part affected.	Character of pressure.	Formula,	Plots the line.	Relationship shown by the line of col. IV.
TUBE Cont'd.	External, Cont'd.	$\Sigma\overline{P}_1 = \overline{P}_1 + \bar{p}_1$ (k)	....	Sum of all pressures at first contact surface in the state of rest.
		$\Sigma\overline{P}_1(\max) = \frac{(R_1^2 - R_0^2)}{2R_1^2} \cdot \rho_0$ (l)	....	Maximum value of the pressures, due to collective shrinkages, which the tube can stand and not be overcompressed when the powder pressure does not support the bore.
		p_1 (m)	p_1P_0	Same as (h) for the jacket. It is internal for jacket, external to bore.
		P_0 (n)	....	General symbol for pressure in the bore, may have $P_0(\theta)$ or $P_0(\rho)$ as a particular value.
		$P_0(\theta) = \frac{3(R_1^2 - R_0^2)\theta_0 + 6R_1^2P_1}{4R_1^2 + 2R_0^2}$ (o)	$P_1P_0(\theta)$	The coordinates of any point on this line show what coincident values of a pressure in the bore, P_0, combined with an external pressure P_1 will just bring the inner surface of the bore to its elastic limit of circumferential strain.
		$P_0(\rho) = \frac{3(R_1^2 - R_0^2)\rho_0 + 2R_1^2P_1}{4R_1^2 - 2R_0^2}$ (q)	$P_1P_0(\rho)$	Similar to the above for the elastic limit of radial strain.

Principle of the diagram for three cylinders.—

Axes are drawn as indicated in Fig. 53, in the upper right-hand quadrant, of which is constructed, for the tube considered as a cylinder subjected to internal and external pressure, a diagram similar to Fig. 39. In the second quadrant is constructed a similar diagram for the jacket considered as a tube subjected to internal and external pressures.

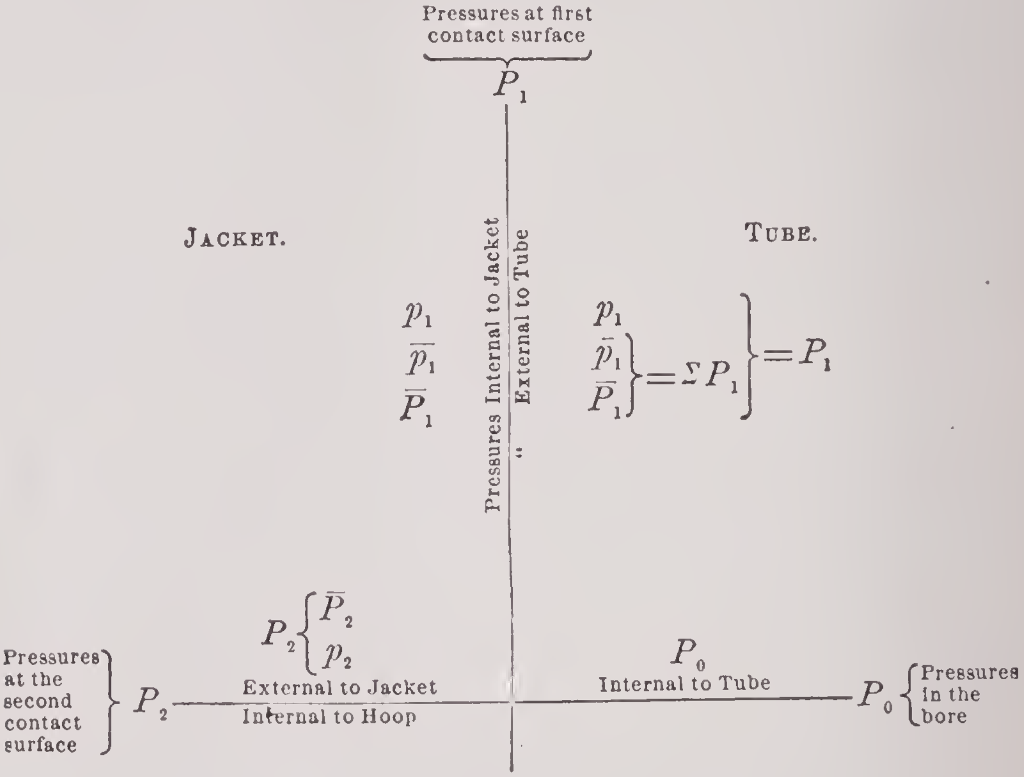


FIG. 53.

For the hoop, only one calculation is necessary, that, $P_2(\theta)$ beyond which the internal pressure of the hoop must not be carried without exceeding the elastic limit of circumferential strain.

For the sake of clearness, the line $\bar{P}_1S_1$ of Fig. 48 is in Fig. 53 plotted in the first quadrant, while the corresponding line $\bar{P}_2S_2$ for the jacket is dropped to the third quadrant.

For any assumed condition of the hoop, jacket, or tube, coincident relationship of the other parts may be traced through the diagram, and effect of modifying one element noted in the others.

The first lines drawn are $P_1P_0(\theta)$, $P_1P_0(\rho)$, $P_2P_1(\theta)$, $P_2P_1(\rho)$, p_1P_0, and p_2p_1, as given by the equations assembled above. Read Fig. 54 in connection with what follows.

The next step is to assume that the system is in action and that the hoop has been brought to its allowable elastic limit as given. The pressure which will do this is $P_2(\theta)$.

Next, with $P_2(\theta)$, now as an external pressure to the jacket, we must find from the line $P_2P_1(\theta)$ or $P_2P_1(\rho)$ what internal pressure we may allow for the jacket. This pressure is usually taken as the least given by either of the lines $P_2P_1(\theta)$ or $P_2P_1(\rho)$. Having determined this value of P_1 we must next find what pressure P_0 in the bore must be used to develop this value of P_1. This is determined by the points in which the horizontal line drawn from the above determined value of P_1 cuts the lines $P_1P_0(\theta)$ and $P_1P_0(\rho)$.

There will thus be two values for P_0 which will produce that value of P_1 which in turn produces that value of P_2 which will bring both hoop and jacket simultaneously to their elastic limit of circumferential strain.

One, $P_0(\rho)$, of the two values of P_0, acting with P_1 will bring the inner surface of the tube to its elastic limit of radial strain.

The other value of P_0, $P_0(\theta)$, acting with P_1 will bring the inner surface of the tube to its elastic limit of circumferential strain.

* If $P_0(\theta)$ as determined above be less than $P_0(\rho)$ then the latter will be disregarded, for we may not admit in any case, that the elastic limit of circumferential extension can be safely exceeded for any part of the system.

If, however, $P_0(\theta)$ as determined above be greater than $P_0(\rho)$, there will be two possible values of P_0, which will lead to different results as one or the other is adopted.

Simply stated, when $P_0(\theta) > P_0(\rho)$, it will require larger shrinkages to produce the required value of P_1 with a value of $P_0 = P_0(\rho)$, than it would with a value of $P_0 = P_0(\theta)$.

As reduced shrinkages produce less strain for the state of rest, and as this is desirable, let us base the shrinkages, with which the cylinders are assembled, upon $P_0 = P_0(\theta)$.

Having now decided upon P_2, P_1, and P_0, assume that the pressure in the bore disappears and that the gun gradually reaches a state of rest.

P_0 will become o; P_1 becomes $\Sigma\bar{P}_1 = (\bar{P}_1 + p_1)$, and P_2 become $\bar{P}_2$. P_1 will fall along a line parallel to the line p_1P_0 and P_2 will

* Birnie, Ord. Notes U. S. A. No. 59.

fall parallel to the line p_2p_1, stopping at that value of P_2 as determined by $\Sigma\bar{P}_1$ as an internal pressure on the jacket.

From the above value of $\bar{P}_2$ and the line $\bar{P}_2S_2$, we get S_2; and from the same value of $\bar{P}_2$ and the line $\bar{p}_1\bar{P}_2$ we get $\bar{p}_1$. Deducting $\bar{p}_1$ from $\Sigma\bar{P}_1$ we get $\bar{P}_1$, and with this and the line $\bar{P}_1S_1$, we get S_1.

If in the state of rest ΣP_1 be equal to or less than $\Sigma\bar{P}_1$(max.) the tube is not overcompressed at the bore and the gun is safe. If, however, ΣP_1 be greater than $\Sigma\bar{P}_1$(max.) we must readjust the values of S_1 and S_2 so as to make the bore safe from overcompression for the state of rest, or better, select an allowable value of $\Sigma\bar{P}_1$ and from this determine S_1, S_2, P_0, etc.

Each one of the foregoing steps may be performed graphically and is indicated in Fig. 54, in sequence, by the lettering *a, b, c, d*, etc.

In this figure it will be seen that pressures $P_0=Oc'=P_0(\theta)$, $P_1=Ob'=P_1(\theta)$, and $P_2=Oa=P_2(\theta)$ will bring the tube, jacket and hoop, simultaneously to their elastic limits of circumferential strain. Also, that the shrinkages based on these values are $S_2=Og'$ and $S_1=Oi$. Also, that the pressure at rest at the second contact surface is $\bar{P}_2=dc$ and $\Sigma\bar{P}_1=Od$. By drawing a line from c parallel to $\bar{P}_2p_1$, we graphically deduct $\bar{p}_1=df$ from $\Sigma\bar{P}_1$ leaving $\bar{P}_1=Of$, with which value of $\bar{P}_1$ we use the line $\bar{P}_1S_1$ to find $S_1=Oi$, as stated above.

271. A note on the line p_2p_1.—This line, to be strictly correct, should be drawn from the point d, Fig. 54, as P_0, p_1, and p_2 should simultaneously become O for $P_0=O$. But as this would necessitate a new line every time the point d shifted, and as the real use of the line is merely to express the degree of the change in p_2 for a change in p_1, it is sufficient to draw it once for all through the origin and use it in the sense of a direction cosine.

272. Fig. 55 gives the following information, as shown by the construction:

If, with $P_2(\theta)=4.389$, we use $P_1(\rho)$, the corresponding value of $P_0(\theta)$ will be 25.04 tons, its maximum possible strength. With the same value of $P_2(\theta)$ and restricting ourselves to $P_1(\theta)$ for reasons given in the previous text, we find that $P_2=4.389$, $P_1=13.445$, and $P_0=23.33$ will just bring the three cylinders simultaneously to their elastic limit of circumferential strain.

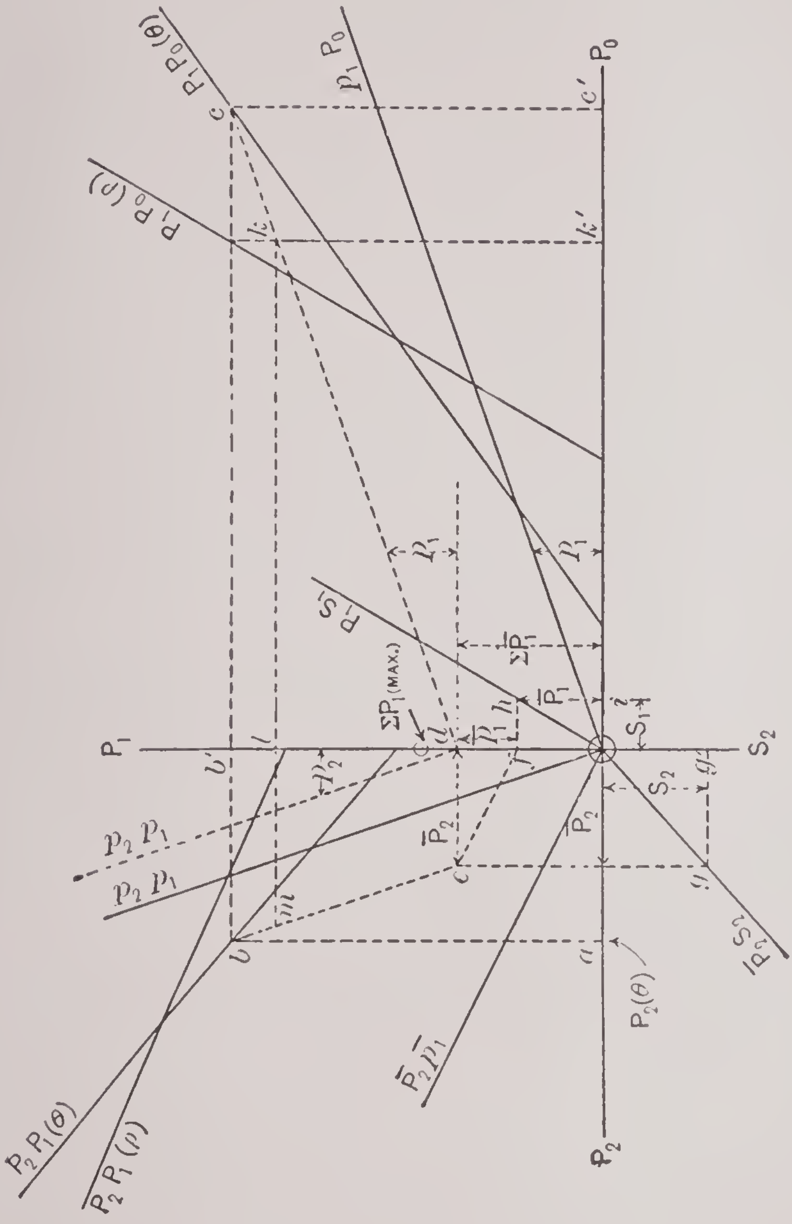

P_1
P_2
P_0
S_2
$p_1\,P_0$
$P_1P_0(\theta)$
$P_1P_0(\rho)$
$P_2P_1(\theta)$
$P_2P_1(\rho)$
$p_2\,p_1$
ΣP_1 (MAX.)
$P_2(\theta)$

FIG. 54

With these values of P_2, P_1, and P_0 the pressures at rest are $\Sigma P_1 = 4.785$, $\bar{P}_2 = 2.70$, and $\bar{P}_1$ slightly less than 3.0 tons. The corresponding shrinkages required are $S_2 = .0210$ and $S_1 = .0118$.

If for practical purposes we adopt the values to the nearest one-thousandth of an inch thus retaining $S_2 = .021$ and making $S_1 = .012$, $\bar{P}_1$ becomes 3.0 tons, $\Sigma\bar{P}_1$ 4.85 tons, and $P_0(\theta)$ becomes 23.4 tons.

If we now call $P_0(\rho)$ our safe limit of pressure in the bore $P_0(\rho) = 18.14$, and when this pressure is exerted in the bore the pressures at the contact surfaces rise to 11.6 tons in the jacket and 4.0 tons in the hoop, returning at rest to 4.85 tons and 2.70 tons, respectively.

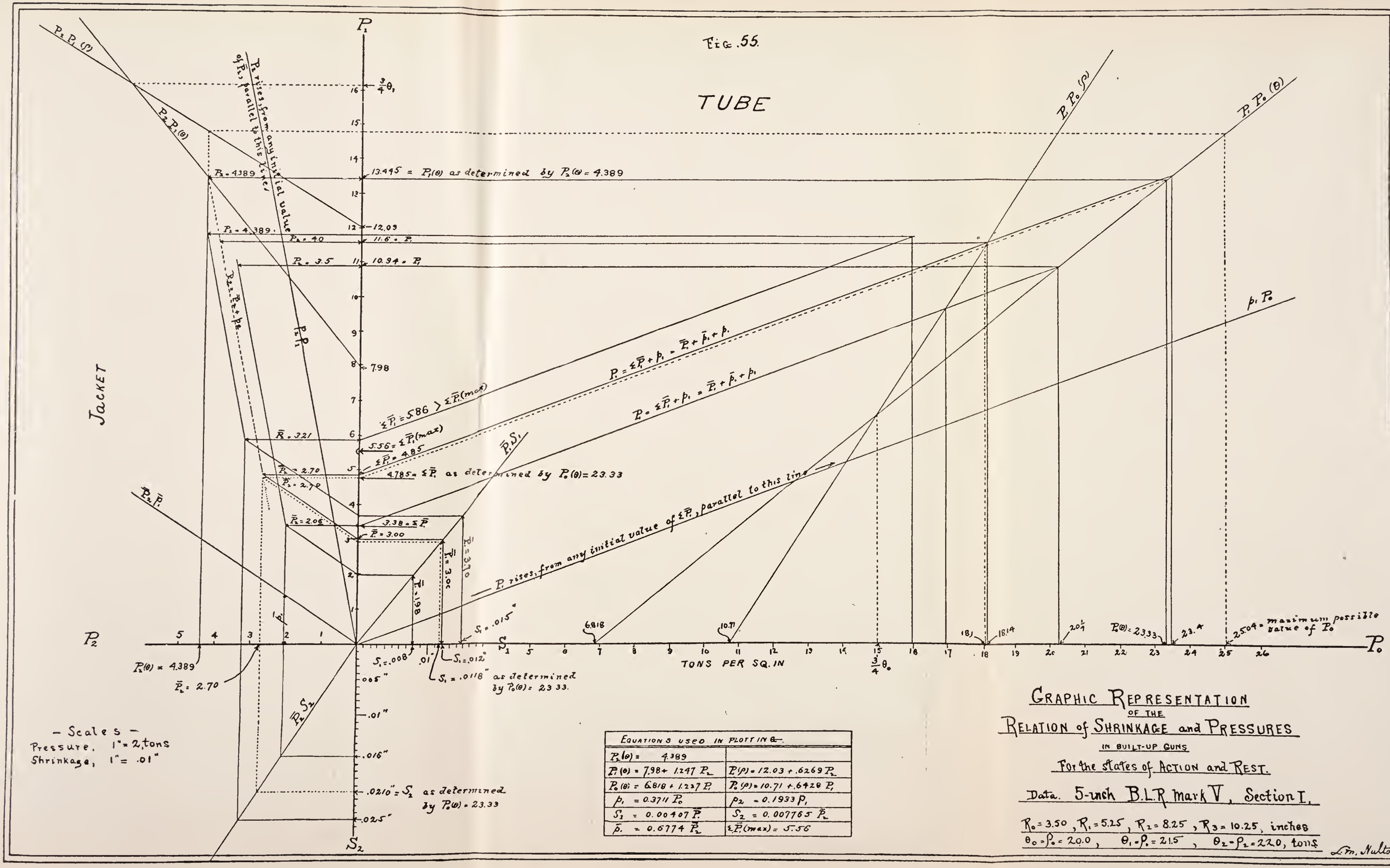
If it became necessary in assigning shrinkages to adopt $S_1 = .008''$ and $S_2 = .016''$, the corresponding value of $P_0(\theta)$, P_1 and P_2 would be $20\frac{1}{4}$, 10.94, and 3.5 tons, respectively. The pressures at rest would be $\bar{P}_1 = 1.98$, $\bar{P}_2 = 2.06$, $\Sigma\bar{P}_1 = 3.38$.

If we limit the pressure in the bore by the value of $P_0(\rho)$ corresponding to $P_0(\theta) = 20\frac{1}{4}$, we will have the safe internal pressure in the bore $= P_0(\rho) = 17$ tons $(\pm)$.

If instead of adopting the values just considered we had assigned $S_1 = .015$, and $S_2 = .025''$, the construction clearly shows that in action a pressure in the bore of 16 tons would quickly bring the hoop to its elastic limit of circumferential strain before the elastic limit of either jacket or tube had been reached.

It shows also that these shrinkages are really unallowable because $\Sigma\bar{P}_1$, due to them, is greater than $\Sigma\bar{P}_1$(max.), and the bore is overcompressed in the state of rest.

The effect, of varying one or both shrinkages, on the working of the gun is clearly indicated by the figure.



Equations used in plotting.	
$P_2(\theta) = 4.389$	
$P_1(\theta) = 7.98 + 1.247\,P_2$	$P_1(\rho) = 12.03 + .6269\,P_2$
$P_\circ(\theta) = 6.818 + 1.227\,P_1$	$P_\circ(\rho) = 10.71 + .6428\,P_1$
$p_1 = 0.3711\,P_\circ$	$p_2 = 0.1933\,p_1$
$S_1 = 0.00407\,\bar{P}_\circ$	$S_2 = 0.007765\,\bar{P}_2$
$\bar{p}_\circ = 0.6774\,\bar{P}_2$	$\Sigma\bar{P}_\circ(max) = 5.56$

CHAPTER VIII.

METALS USED IN ORDNANCE CONSTRUCTION.

Definitions.

273. Stress and strain.—When a force is applied to a body, the effect produced depends upon whether or not the body is free to move. A force applied to a free body produces motion. A force applied to a fixed body produces change of form. (See Art. 177.)

Stresses are of different kinds, depending upon the manner of application of the force, as *tensile, compressive or torsional* stress.

A torsional stress is a compound stress, and may be resolved into a "*tensile stress*" on some elements of the material and a "*compressive stress*" on others.

Each kind of stress produces a corresponding strain, or effect on the material: The tensile stress produces *elongation;* the compressive stress, *compression.* Since all stresses may be resolved into tensile and compressive stresses, all strains may be resolved into elongation and compression.

274. Elasticity, elastic strength, modulus of elasticity, set.—The *elasticity* of a metal is the property it possesses of resisting permanent deformation when subjected to a stress.

All experiments and experience agree in establishing the five following laws for cases of simple tension and compression, which may be regarded as the fundamental principles of the science of the strength of materials:

(1) When a small stress is caused in a body, a small deformation is produced; and on the removal of the stress, the body springs back to its original form. For small stresses within the "elastic limit," then, materials may be regarded as perfectly elastic.

(2) Under small stresses the strains are proportional to the forces which produce them (Hooke's law), and the ratio of stress to strain is a constant for any given material (*i. e.,* Modulus or Coefficient of Elasticity). (See Arts. 181 and 184.)

(3) When the stress is great enough, a deformation is produced which is partly permanent; that is, the body does not spring back entirely to its original form on removal of the stress. This

permanent part is termed a *set*. In such cases, the deformations are not proportional to the stresses. It is a fundamental law of all engineering construction that materials be not strained beyond the elastic limit.

(4) When the stress is greater still, the deformation rapidly increases, and the body finally ruptures or fractures, and actual division of the solid occurs. The maximum stress a material will stand without fracture is called its *ultimate strength*.

(5) A sudden stress, or shock, is more injurious than a steady stress, or than a stress gradually applied.

The words "small" and "great," used in stating these laws, have very different values and limits for different kinds of materials and stresses.

General Remarks on Metals.

275. Physical properties of metals.—Metals have certain properties, which are of great importance in the case of metals used in gun construction. These principal properties are *malleability, ductility, hardness, toughness, tensile strength,* and *elasticity*.

(1) *Malleability*.—A metal is said to be *malleable* when it may be permanently extended in all directions without rupture, by pressure (as in rolling) or by impact (as in hammering).

(2) *Ductility*.—A metal is *ductile* when it may be extended permanently by traction, as in wire drawing. Only malleable metals are ductile, but their ductility is not necessarily in the same ratio as their malleability.

(3) *Hardness*.—A metal is said to be *soft* when it yields readily to compression without fracture, and does not return to its original form on the removal of the compressive stress; and on the other hand, a metal is said to be *hard* when it does not yield readily to compression; that is, when the ratio of the compressive stress to the permanent strain produced is very great. The terms *hardness* and *softness,* however, are only comparative when used in describing metals; thus, we have hard and soft leads, while any sort of lead is soft as compared with wrought iron, which latter is called soft when compared with cast iron.

(4) *Toughness* in a metal is a relative term to express the power of resisting fracture by bending or torsion, and is measured by the number of times to which a definite section of the metal

can be bent through a certain angle on either side of the perpendicular without any fracture.

(5) *Tensile strength.*—The *tensile strength*, or ultimate strength, of a metal is the unit stress required to produce fracture. Thus, if a bar whose cross-section is A breaks under a tensile stress P, the tensile strength of the material is $\frac{P}{A}$.

276. Hardening.—When steel is heated to a red heat and suddenly cooled, for example, by plunging it in cold water, it is hardened. The more sudden the cooling, the greater is the hardness attained. Thus, cooling in water gives a greater degree of hardness than cooling in oil. The term usually employed to express rapid cooling of heated steel by plunging in water or oil is *quenching*. It results in an increase in tensile strength and elastic limit, but with a corresponding decrease in toughness. The steel becomes hard and brittle.

277. Tempering.—Tempering is the process of mitigating or "letting down" the hardness of steel after quenching. It is brought about by careful and gradual reheating to a temperature of 200° to 300° C., depending on the degree of temper required, and then immersing in oil or water, or cooling in the air. This reduces the brittleness caused by quenching, removes some of the hardness, and increases the toughness of the steel.

278. Annealing.—Just as tempering lets down somewhat the extreme hardness and brittleness of steel that has been quenched, so heating to a low red heat and then allowing the steel to cool slowly removes all the hardness induced by the original quenching process. This removal of hardness and brittleness by reheating and slow cooling in known as *annealing*. Not only does it soften the metal, but also it relieves any internal strains caused by working or quick cooling.

279. As we are now especially interested in the metals used in gun, armor, and projectile making (steel and nickel-steel), only a brief mention will be made of the others.

280. Copper, in its pure state, is too weak and soft for construction purposes. It is used for rotating bands of projectiles, and for electrical fittings and wirings.

281. Bronze, an alloy of copper and tin, is expensive, is too soft for the bores of large rifled guns, is injured by the heat of high

charges, and is liable to flaws due to the segregation of its constituents. It is very ductile, is tough, but is low in elastic limit and tensile strength. It is now used for minor parts subject to no great strain, as sight brackets, hand wheels, liners and bushings to avoid the wear of steel against steel, etc.

282. **Brass,** an alloy of copper and zinc, is used in parts of the minor attachments, such as the firing connections, and for cartridge cases, primers, etc.

283. **Cast iron** is cheap, easily worked, but of low elastic limit and tensile strength. It can be fused and cast without difficulty, and is comparatively hard. It is not malleable, and cannot be welded, and is brittle. Castings are very uncertain in character, due to the method of manufacture. Many, apparently perfect on surface inspection, develop serious flaws in machining, and have to be rejected. Cast iron is not now used for either guns or mounts.

284. **Wrought iron** is almost infusible, but is readily welded. Its tensile strength and elastic limit are low; but on account of its ductility, it requires a large amount of work to extend it from its elastic limit to fracture, which makes it a comparatively safe material to use because it will give evidence of weakness before actual fracture takes place. The bores of wrought iron guns have been permanently indented or bruised by moderate powder pressures, the metal not being hard enough. This is a serious defect under the high pressures modern guns must stand. Wrought iron is no longer used in either guns or mounts.

285. **Cast steel** has a higher tensile strength and elastic limit than wrought iron, but not so great a ductility. As forged steel is used exclusively in the manufacture of modern naval guns, so cast steel is used for mounts, and it is only the ability to obtain steel castings reasonably free from dangerous flaws that has made the strong, compact, modern naval gun mount possible. The only difference between cast steel and forged steel is that the latter has been *worked,* either by *hammering* or by *pressing*, which results in a rearrangement of the molecules and a marked improvement in the physical qualities. But it is also possible to effect considerable improvement in the physical properties of steel castings by treatment, that is to say, by annealing and tempering.

286. **Forged steel** combines more good qualities for use in modern guns than bronze, cast iron, wrought iron, or cast steel. It

is easily fused, is malleable, and is more or less weldable, according as it is soft or hard. It is tough and elastic, with a much higher elastic limit and tensile strength than wrought iron or cast steel. Its elastic limit, or elongation within that limit, is much higher than for the other metals above noted; and this quality makes it especially suitable for gun making, in view of the strains which are set up in guns by heavy charges.

287. **The properties of wrought iron** are not sensibly modified by temper, which is ordinarily expressed by saying that wrought iron does not temper. Pure wrought iron contains no carbon at all; commercial iron may have as much as .30 per cent carbon. Soft or extra low steel may contain as low as .15 per cent carbon; there is, however, a great difference in the physical qualities of the two metals, due to the methods of manufacture.

288. **Steel proper** may be said to contain from .20 per cent to 2.00 per cent carbon, and cast iron from 2.00 per cent to 5.00 per cent. The properties of certain cast irons are considerably modified when, after having been liquefied, they are cooled suddenly; therefore, we may say, from this point of view, that cast iron takes temper like steel.

289. To state in a few words the characteristics which may serve to distinguish wrought iron, steel, and cast iron, we may say: Wrought iron is forgeable, weldable, practically infusible, and *does not temper;* steel is forgeable, weldable, fusible, and takes temper; cast iron is neither forgeable nor weldable, it is relatively very fusible, and is susceptible of being tempered.

Steel in General—Composition of Steel.

290. **Definition of steel.**—Reasoning from the foregoing, steel is a *fusible, malleable alloy of iron produced in any way whatever, and containing a smaller proportion of carbon or other hardening element than is contained in cast iron, and is capable of receiving temper.*

291. **Process for obtaining cast steel.**—There are a variety of processes for removing a portion of the carbon from cast iron and producing steel, among which may be mentioned: (1) Melting in crucibles, giving *crucible steel;* (2) melting in the electric furnace, giving *electric furnace steel;* (3) melting in the Siemens or Siemens-Martin open-hearth furnace, giving *open-hearth steel;* (4) blowing air through molten cast iron in the Bessemer con-

verter, producing *Bessemer steel.* In whatever way made, the material is essentially the same, depending for its properties upon its chemical composition and physical structure.

The various processes of making steel mentioned above are all described in detail in works on Mechanical Processes. No description of the methods, therefore, is given here.

292. High and low steel.—In consequence of the extension given to the word *steel,* we have to-day under this name metals which present differences as regards both composition and physical properties. Hence, the different varieties of steel have been distinguished by the proportion of carbon they contain—sometimes by percentage, and sometimes by more or less characteristic names. When the metal contains a large proportion of carbon, it is ordinarily called *high* or *hard steel.* If the proportion of carbon is small, it is called *low* or *soft steel;* if still smaller, *extra low steel.* In some manufactories, for example, the name of *low steel* is given to a metal containing .20 to .25 per cent of carbon, and a metal in which the proportion of carbon is less than .20 per cent is designated *extra low steel.*

All steel contains more or less carbon, together with varying amounts of certain other elements, the principal ones being manganese, sulphur, phosphorus, silicon, copper, and arsenic. Of these elements, sulphur and phosphorus especially are kept as low as possible, since their presence is detrimental to the steel. Certain other elements are sometimes found in the iron ore used in making steel, or are added as alloys, in certain definite quantities, with the object of giving desired qualities to the product; among these are: Nickel, vanadium, chromium, aluminum, tungsten, molybdenum, uranium, and titanium. Steel containing carbon and elements of the first group mentioned is usually called *carbon steel;* if it contains, in addition, some one or more of the elements of the second group, it is called an *alloy steel,* as *nickel steel, chrome steel,* etc., depending on the element or elements present.

293. Physical properties—how obtained.—The physical properties of any steel depend on: (1) Chemical composition, (2) heat treatment, (3) the amount and kind of mechanical work to which it has been subjected.

(1) The chemical composition of steel influences both its physical properties and its structure, owing to the definite compounds

formed by the combinations of carbon, manganese, sulphur, phosphorus, and other constituents.

(2) Heat treatment includes the whole of the thermal conditions through which the metal is passed, and embraces both heating and cooling by different methods and under different conditions.

(3) Mechanical work to which the steel is subjected consists in rolling or forging to reduce the ingot to the desired shape and to impart to it the desired qualities.

Steel for Ordnance Purposes.

294. Castings.—Steel castings for ordnance purposes are used chiefly for gun yokes, sight brackets, and the various parts of gun mounts. They are produced by either the open-hearth or the electric process, the object in either case being to obtain a steel that is reasonably free from injurious elements. The excellence of steel castings is largely determined by the method of casting.

295. Gun forgings.—In the manufacture of steel for gun forgings, the Krupp works in Germany originally used the crucible process; later they adopted the electric process. In the United States the open-hearth process has been, and is still, extensively used, though at present a great deal of steel for gun forgings is made in the electric furnace.

The crucible process has many advantages in obtaining steel of great purity, but on account of the impossibility of insuring identical composition in all crucibles, uniformity of composition cannot be obtained in ingots of the size required for large gun forgings. In the open hearth or the electric furnace, on the other hand, a single charge equal to the combined contents of a good many crucibles, can be melted down, producing a molten mass of steel of homogeneous composition and a high degree of purity, and of a quantity sufficient to produce the large ingots necessary for gun forgings.

Carbon steel is used for certain gun forgings, notably liner forgings and some of the outer hoops of large caliber guns. When so used it is generally spoken of as *gun steel*. Alloy steel is used for the tube, the jacket, and certain hoops—chiefly those directly over the tube and jacket—which are subjected to the most stress on firing, and require material of high-tensile strength and elastic limit. The particular alloy used is *nickel*, producing *nickel-steel*

forgings. A chrome steel is avoided in gun forgings for the reason that it is too brittle and is liable to crack on shock of firing.

The following table gives the average chemical composition of gun forgings:

	Gun Steel.	Nickel Steel.
Carbon	.50%	.40%
Manganese	.70 "	.70 "
Silicon	.27 "	.27 "
Phosphorous	.03 "	.03 "
Sulphur	.03 "	.03 "
Nickel	....	3.00 "

296. Armor.—The armor used on ships of the U. S. Navy is face-hardened, excepting the plates for turret and conning-tower tops, which are of special-treatment steel. Face-hardened armor is designated as Class A, and the special-treatment steel plates as Class B.

Protective-deck plating and splinter bulkheads are made of special-treatment steel, but are not classed as armor.

Class A armor may be cemented or non-cemented. For non-cemented armor the carbon content is somewhat greater than for cemented armor. The composition is predetermined, being low-carbon steel, containing inseparable ingredients of phosphorus and sulphur, the percentage of which it is endeavored to keep at a minimum, and nickel, chrome, silicon, and manganese. (See Art. 587.)

297. Projectiles.—Steel for projectiles is made by the crucible, open hearth, and electric processes. (See Art. 646.)

298.

RECAPITULATION.

Purpose.	Kind of steel used.
(1) Gun-mounts, yokes and sight brackets.	Alloy steel castings.
(2) Guns	Gun steel forgings for liners and outer hoops of large caliber guns.
	Nickel steel forgings for tube, jacket, and inner hoops.
(3) Armor	Class A,—Alloy Steel, pressed or rolled, face-hardened.
	Class B,—Special-treatment alloy steel, pressed or rolled, not face-hardened.
(4) Protective deck and splinter bulkheads.	Special-treatment alloy steel, pressed or rolled.
(5) Projectiles	Alloy steel, forged.

Method of Manufacture of Steel and Alloy-Steel Gun Forgings.

299. Furnace practice.—Nickel-steel and gun steel for gun forgings are made in acid open-hearth furnaces and in electric furnaces, because of the increased probability of blowholes and gas bubbles in steel converted by the basic process, due undoubtedly to the fact that such steel is likely to be more highly charged with oxygen. The furnace charge is made up of about one-third pig iron low in phosphorus and about two-thirds plain or nickel-steel scrap, such scrap being parts of old ingots, cuttings, and turnings. The exact proportions of pig and scrap depend on the quality and quantity of the scrap obtainable, and also on the analysis of the pig iron (particularly its silicon content); but the pig iron generally constitutes from 20 to 30 per cent of the charge. The scrap, if the product is to be nickel-steel, contains from 2 to $2\frac{1}{2}$ per cent nickel. From six to eight hours are required to break down and thoroughly melt the charge, and as soon as this occurs samples are taken. A fracture test enables an experienced person to closely estimate the percentage of carbon contained in the charge. Other samples are sent to the chemical laboratory, where analysis is made for carbon, manganese, silicon, sulphur, phosphorus, and nickel. The nickel is not oxidized, and remains constant, and the amount to be added, if any, is determined from the analysis and introduced in the form of pure nickel blocks or "plaques."

Every half-hour after the charge is melted a carbon test is made, until the carbon has been reduced to the desired percentage by oreing down. This consists of adding iron ore from time to time, Lake Superior hematite being generally used, the reaction being $Fe_2O_3+3C=2Fe+3CO$. For nickel-steel tubes and liners the carbon is reduced to between .35 per cent and .42 per cent, but for "gun steel" the amount of carbon will run between .42 per cent and .50 per cent. From the results of the analyses the various necessary additions are made to bring the manganese and chromium up to the required amount. Ferro-manganese, or spiegeleisen, is added to increase the carbon and manganese, the former being used when a smaller increase of carbon is desired. Ferrochrome is added if necessary. Loam is put in to increase the slag, limestone to thin the slag.

From 10 to 20 hours after the bath is melted, it is tapped into ladles. Ferro-silicon is added to the ladle to bring the silicon up to the required amount. The molten metal is allowed to run into a large refractory-lined ladle, and as the tap hole of the furnace is below the slag line, only a small amount of slag goes into the ladle, and this remains at the top; by using bottom-pouring ladles the amount of slag is still further reduced.

300. Ingots.—Two kinds of ingots are used—the corrugated ingot for gun forgings and the fluid-compressed ingot. The ingot molds are tapered from top to bottom, the top being smaller. The size of the ingot is its diameter at the middle of its height. The ingots are top- or bottom-poured indifferently; some manufacturers top-pour all ingots, others bottom-pour, and some one-half bottom-pour and one-half top-pour. A tong hold is left at the top of ingots to assist in handling, which also serves as a sink-head to take care of most of the slag, segregation, and piping.

301. The Whitworth process of fluid compression frees the cylindrical ingot of much of its gas content and thus reduces the amount of blowholes and piping. The liquid metal is subjected to slowly increasing pressure until about 2300 pounds per square inch is reached. This pressure is held for four or five hours, or until the metal has entirely solidified.

The last samples, three in number, are taken during the pouring of the ingot; two are analyzed for carbon, manganese, silicon, phosphorus, sulphur, and nickel, and the result of the analyses is sent to the forge, where it is used in determining the forging heat. The third sample is taken to a small forge near at hand and, without treatment, is forged into test bars to ascertain the approximate physical qualities; this, known as the "heat test," gives an idea as to what can be expected of the metal.

As soon as the ingot is cold enough, it is stripped from the mold and a number is placed on it; this number remains with it for identification until it has passed through all of the processes and forms a part of a finished gun. The ingot is immediately taken to an annealing furnace, where it is slowly and uniformly heated. Soft coal is used for heating, and the furnaces are provided with baffle walls for protecting the ingot from the direct action of the flame. The ingot enters the furnace at a temperature of about 1400° F., and is kept at this temperature for about five hours, after

which time the fires are allowed to die down and the ingot cools slowly with the furnace. From three to four days are required for the cooling of a large ingot.

The ingot is now sent to a machine shop, where it is slung on a large lathe, and the specified amounts of top and bottom discard are removed. If the ingot is to be used for hollow forging, it is put in a boring mill and rough-bored to the required diameter. After the discard has been removed, and after boring (if this operation is required), the ingot, if not to be forged in one piece, is cut into blocks of the required sizes. This is done in the lathe used in cutting off the discards.

A separate number is stamped on each block made from an ingot, using the ingot number as the first part, and following it with letters and numbers to indicate the relative position of the block in the ingot. These numbers always begin at the breech or bottom end of the ingot; thus, if ingot No. 12345 were cut into four pieces, the bottom block would be No. 12345B1, the second block from the bottom No. 12345B2, and so on. If the whole ingot, after discards have been removed, is to be used in a single forging, it carries its ingot number and is designated B1. If any of these blocks are afterwards cut into smaller pieces, the number given these pieces would be No. 12345B1F1, No. 12345B1F2, etc., numbered from breech end of block. (The "F" stands for "forging.")

Before leaving the machine shop the block is examined by a sub-inspector for signs of piping, blowholes, and other defects, and the amount of discard is checked.

302. Forgings.—Forgings for pieces whose finished interior dimensions are small are forged solid; larger pieces are bored before being forged. For instance, the tube and jacket and "B" hoops of a 14-inch gun would be forged solid; the "C" and "D" hoops would be bored before being forged.

From the machine shop the block is taken to the forge, where it is brought to the desired forging temperature in an acid-lined regenerative, producer gas furnace, or other similar furnace. This temperature is usually about 2100° F. If the block is a long one, one end is heated at a time; the other end, projecting from the furnace, is used for handling the piece during the forging operations, the ends being alternately heated and forged under a

hydraulic press. Small blocks go entirely in the furnace, and are heated uniformly. The length of time required to bring the block to forging heat depends on the size of the block, and the quality of the steel. Great care is taken not to heat too rapidly, this being particularly important with alloy steels.

The block having been brought to forging heat, it is balanced by means of a porter bar, and taken by an overhead crane to the hydraulic forging press. There the operation depends upon the kind and shape of forgings to be made.

If to be forged solid, the block is forged down and drawn out by repeated workings, the forging being supported in a V-shaped anvil under a slightly concave die secured to the *tup* or head of the press, the pressure being applied gradually for about three seconds, with about one-second intervals between pressures. As the forging operation is generally discontinued when the block has cooled to about 1550° F., several heats are necessary for tubes and liners.

The hollow forgings are forged on a mandrel which snugly fits in them. The forging is done as above described, between the V-shaped anvil and concave tup, as in the case of solid forgings; and in this manner the hole is not enlarged, but the wall thickness is reduced, and the metal is drawn out along the mandrel. With large forgings about eight heats are required for this operation, the mandrel being removed each time before the forging is put back in the furnace.

Short hoops of large diameter are forged on an *enlarging bar*, the ends of which are supported on rests, or *jacks,* on each side of the press, with the forging hanging free on the bar between them and under the tup. By this means the thickness of wall is reduced and the hole enlarged without an appreciable change in the length of the forging. If it is necessary to lengthen a hoop thus enlarged, a mandrel is used for drawing it out as explained above.

Breech bushings, or screw-box liners, are first forged or drawn down before being bored. Thus, a forging of this kind for a 12-inch or 14-inch gun is made from an 84-inch corrugated ingot, forged down to a diameter of 54 inches, annealed to relieve it of forging strains, bored through the center, heated for reforging, put on an enlarging bar, and the hole enlarged to the required dimensions. As these bushings are made of nickel-chrome steel,

which is very apt to crack while under the press, they must be carefully nursed, and two or more reheats are necessary—one called the shaping heat, and one the finishing heat. Large breech bushings are always forged in pairs with their breech faces together, each end of the forging being forged down in steps as required by the drawings. After forging and subsequent annealing, they are cut apart in the lathe before being sent to the treatment department.

When the forging operation has been completed, the manufacturer sends a forging report and sketch of the rough forging to the inspector. The report contains the order number, drawing number, description of article, forging number, weight of discard, top and bottom, and size of bore. The sketch shows the general shape of the forging, with dimensions, and from this the forging reductions are figured.

From the forge all gun forgings are returned to the annealing furnace, and there annealed at a high temperature (about 75° above critical) for a considerable length of time to remove strains and to break up the previous structure. This annealing is done generally in an oil furnace. A button is taken and examined under the microscope to determine whether the metal is ready for tempering.

303. Machining.—After annealing, the forgings are sent to the machine shop, where the rough ends are cut off, steady rest bearings turned, and the scale removed. If a solid forging, it is put in a boring lathe and bored out to about 1 inch less than finished dimensions. When these operations are completed, the forging is examined for cracks, signs of piping, or other defects. From the machine shop the forging is sent to the treatment department. On short pieces sufficient metal is left on the inside and outside to allow for warping in treatment; on larger pieces the forgings are machined to the required rough forging dimensions, and if warped in treatment are straightened under a press. Sufficient excess metal is left on each end of the forging to provide test specimens required by the specifications.

304. Treatment—tempering and annealing.—The method of treating and annealing the forgings, and a general description of the furnaces used by one of the larger manufacturing plants, are here given without any attempt to discuss the theory of heat treat-

ment or special processes or details. Gun liners, tubes, and hoops are lowered vertically by means of holding rods and crane into pit furnaces and there brought to heat for tempering. These pits are of various sizes and depths, the largest being 60 feet deep and 70 inches in diameter. They are lined with fire-brick and heated with producer gas supplied through a number of nozzles or tuyères piercing the furnace in rings equally spaced; the direction of these nozzles being tangential to the walls of the furnace, the forging is not exposed to the direct action of the flame. The length of time that a forging remains in a furnace depends on the size of the forging, its carbon content, and the temperature of the furnace. Ten to 12 hours are generally required to thoroughly soak a forging to the desired temperature.

The oil wells into which the forging is immediately immersed after removal from the furnace are about the same size as the heating pits, and are also sunk in the ground. Forgings are immersed in the direction of their longitudinal axis. The oil is kept continually in circulation by means of a pump which forces it up through the bottom of the well, the overflow being carried off by a pipe at the top to a tank outside the building. After about 12 minutes have elapsed, the forging is taken out and put into the annealing furnace, where it is supported, in a horizontal position, on narrow uprights, and gradually brought to the desired temperature. This takes from six to eight hours. The annealing furnaces are heated with producer gas, and the forging is protected from the direct action of the flame. Self-recording pyrometers are used for measuring the temperatures. After being brought to proper heat, the forging is allowed to cool slowly. This is accomplished by a complete or partial reduction of the flame, as may be required, depending on the condition of the furnace. When cooled to about 300° F., the forging is removed from the furnace.

When entirely cool, the forging, if a tube, liner, or long hoop, is tested for straightness; and if warped enough to make this operation necessary, it is again heated (not over 850° F.) and straightened. It is then re-annealed from a temperature slightly above that given it for straightening. The forging is now ready for the company's test. Trial bars are taken, and if, in the opinion of the company, the forging is in proper condition, official submission is

made on a form which gives the forging number, description, and order number, and on the back of the form the record of the last trial tests. Upon receipt of this form the inspector refers to his records; and if the treatment of the piece is satisfactory, the official test bars are laid out as prescribed by the specifications. These bars are slotted out and machined in a special shop, which is a branch of the treatment department and wherein only this class of work is done. The stamping of test bars and the witnessing of the test is done by a sub-inspector.

305. Determination of physical properties.—When steel for any of the above purposes is produced, tests are made to establish its suitability for the particular purpose for which it was intended. These tests involve subjecting specimens of the metal to the action of different stresses in testing machines, and observing, by means of accurate measuring instruments, the deformations produced by these stresses.

306. Testing machines.—The testing machines are generally a combination of levers for recording the stress, and a system of gearing or hydraulic machinery by which the stress is produced.

Specimens are usually prepared to an adopted shape. In the case of gun forgings they are cylindrical, and are turned to the same diameter for a certain length, usually not less than 2 inches and not more than 10 inches for tensile tests; and in addition, ends are allowed for the purpose of attaching the specimen to the machine. For compressive tests the specimen is also cylindrical, the height being twice the diameter. The capacity of the machine limits the diameter of these specimens.

In making a tensile test, the specimen is marked at two points as far apart as the finished length between grips will allow, and the length is carefully measured between these points. The diameter is also measured by micrometer calipers. It is then placed in the machine and subjected to successive tensile stresses, the elongation being noted for each stress, both when the load is on and after it has been removed.

307. Specifications governing the manufacture of ordnance material, which are changed from time to time to keep abreast of the best metallurgical practices and results, state the physical requirements the material must fulfil, and these requirements are carefully checked up by inspections, by analysis, in the testing machines, and by various proof tests at the proving ground.

308. A curious and anomalous condition in ordnance requirements can be seen by an inspection of the table of strengths for gun forgings.

It will be seen, from this table, that for the forgings of the larger guns the hoops are required to be stronger than the jackets, and the jackets stronger than the tubes.

It is desirable that the opposite rule should obtain, and that the tube should be the strongest part of the structure.

Explanation is found in the fact that it is impossible to make a large mass of steel as nearly perfect as a small piece. The smaller the forging the more uniform its texture and the more readily and the more perfectly will it yield to the processes of annealing, tempering, etc., the processes that affect its tensile and elastic strength. The Navy Department is forced to recognize these facts in its specifications.

CHAPTER IX.

DETAILS OF CONSTRUCTION OF NAVAL GUNS.

309. The major caliber guns for the naval service are manufactured at the Naval Gun Factory and at private plants, such as the Bethlehem Steel Co. and Midvale Steel Co., and also at the United States Army Arsenal, Watervliet, N. Y. The greater portion of the work, however, is done at the Naval Gun Factory, and the method of manufacture and inspection in use there are herein described.

Preliminary.

310. The following general remarks apply to all main-battery guns, and will be followed by a detailed description of the assemblage of the 14-inch gun.

Parts of a gun.—(1) A modern built-up gun is composed of a *tube* and *hoops*. They are designated as the A tube, and the B1, B2,..., C1, C2,..., D1, D2,..., etc., hoops.

(2) The B1 hoop, usually called the *jacket*, is immediately over the rear end of the tube and extends well forward on it.

(3) Hoops over the forward part of the tube are called *chase hoops*.

(4) Hoops over the jacket are called *jacket hoops*.

(5) *Locking hoops* are those which hold two adjacent parts together. Inner ones are shrunk on; outer ones may be screwed or shrunk on.

The present tendency is to omit the term "jacket," using simply the term "hoops" with the proper designation.

311. Receipt and assignment of forgings.—(1) Forgings, when received at the gun factory, are weighed and examined for the marks required at the steel works and by the naval inspector at those works. No work is to be done unless these marks are found. The forgings are measured to see if they are of proper dimensions to work out to finished drawings; only .02 inch tolerance is allowed over the drawing dimensions for the forgings. An examination is made for gouges, etc., and for defects in the forgings which would not disappear in the finish machining.

(2) All forgings in any gun are from the same steel works, if practicable.

312. Setting the forging in the lathe.—(1) The forging is brought to the lathe by a crane, and one end—the breech end, for instance—is gripped by the four to six large jaws on the face plate. The muzzle end is likewise gripped by a *pot center,* a large iron ring with several arms screwing through it radially.

(2) The forging is now on live centers. By revolving the forging and screwing the jaws of the face plate in or out, the breech can be centered, as shown by the mark of a tool on the surface of the forging.

(3) The muzzle end is similarly centered. Then the forging is revolved while the tool is run along its carriage. This is done to see whether the forging is warped. Should it be warped, the screws at each end are moved so that the work is thrown to one side or the other to offset the warping. If the forging is so badly warped that it cannot be trued up by this means, it is rejected. A surface is now turned near the muzzle end for a steady-rest. In all long work, one or more steady-rests are used to prevent springing, and the work must be supported by them in boring. The steady-rest is placed in its bearing, and the pot center is removed so that the balancing rod can be inserted and the eccentricity of the bore be noted. It may be necessary, because of eccentricity of the bore, to throw the center a little to one side or the other, but in any case there must be sufficient metal both inside and out to work out to the finish dimensions. When the direction is finally determined, the steady-rest surface is trued up, if it has been thrown out, and surfaces are turned for additional steady-rests.

(4) A bearing is also bored out at the muzzle end, in which is to be placed a dead center for use in turning. For boring, the work is supported in the steady-rests.

313. Turning.—All except very short hoops are at once given a rough cut, on the outside, to remove the scale and take out the spring. This cut is only made deep enough to remove all scale, though in the case of a badly warped forging this may require a deep cut on one side and a shallow one on the other. In this and all turning, the work is revolved while the tool is fed along in its carriage Fig. 1, Plate I, shows the forging for a 14-inch tube, set for turning.

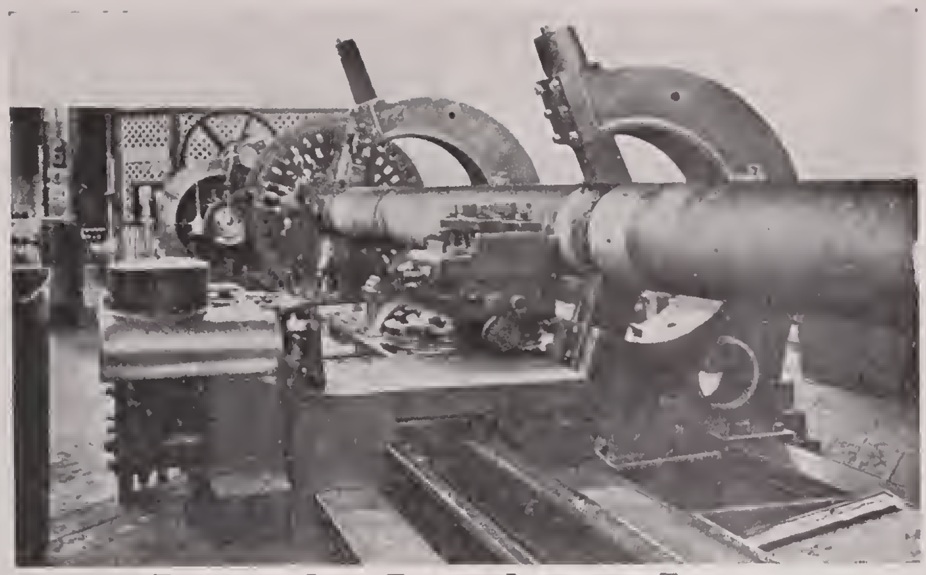


FIG. 1.—14-INCH TUBE IN LATHE FOR TURNING.

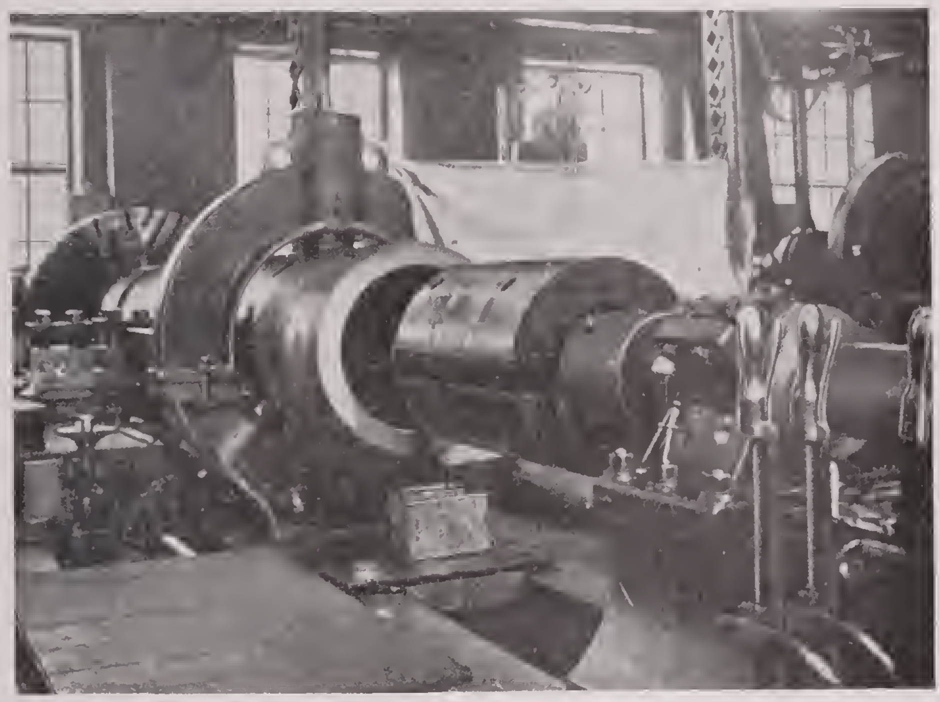


FIG. 2.—14-INCH CI HOOP, SET FOR BORING, SHOWING PACKED BIT.

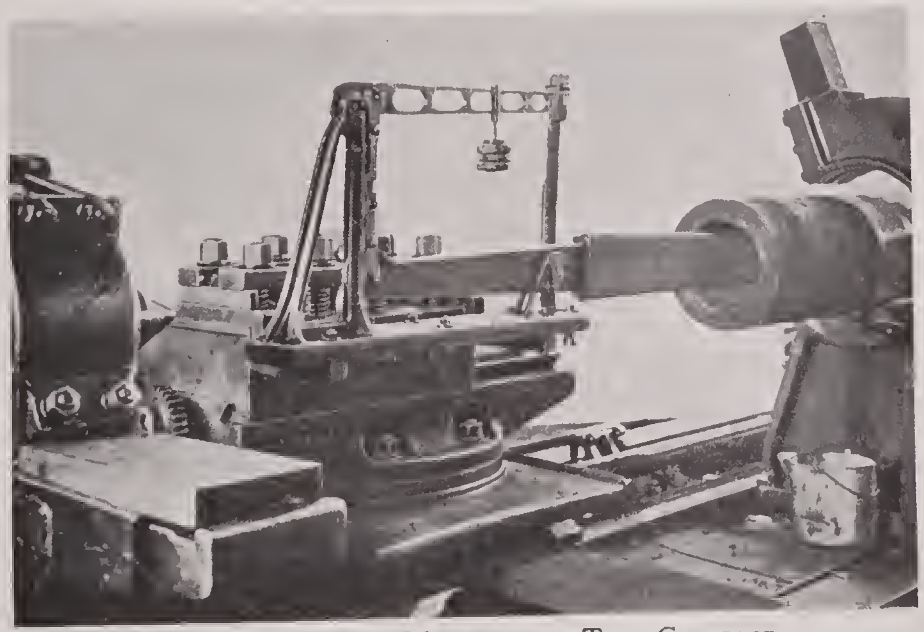


FIG. 3.—INDICATOR MOUNTED ON TOOL CARRIAGE.

This rough cut is the only outside one taken until after the parts to go on over the piece have been bored and star gauged and the shrinkage sheets made out. Then the turning is continued, sometimes using as many as four tools at the same time on two or more carriages. For finishing cuts, tools 1 to 2 inches wide are used, and dimensions are kept correct to .001 of an inch. Steel snap gauges previously set by steel points of known lengths are used to get the diameters.

314. Boring.—(1) For boring short hoops of large diameter a *boring bar* is used. The tool is set on the end of the bar to give the proper cut, and fed along by the carriage as the work revolves.

(2) For long cylinders there would be too much spring in the boring bar, and *packed bits* are used. These are cylinders of oak wood, on iron frames, carrying two tools. The wood is a few thousandths of an inch larger than the hole to be cut, so that, by its forcing, the tools are held rigidly and accurately. Fig. 2, Plate I, shows a 14-inch C1 hoop set for boring, with the packed bit used.

(3) Frequent inspections are made during the boring to see that the hole is true, as, owing to wear of tool, spring of metal, etc., errors constantly creep in. The bit is first carefully centered in the lathe by mounting it on its bar and revolving it while a small spring indicator, mounted on a small base, is pressed against it. This indicator shows any eccentricity to .001 of an inch. By putting liners of thin metal or paper between the stem of the bit and the socket in the end of the bar, it is moved until centered. Then the cut is started, the bit being run in about 8 inches and then withdrawn. The hole is "*indicated*" with the instrument later described, and is tested with steel points set at right angles, to see that it is of the proper diameter. If satisfactory, the bit is again entered, and the cut is continued. Every few feet the bit is withdrawn and the bore is indicated and tested with points for diameter—the frequency of this testing depending on whether the cut is a fine or a rough one, and on what the first measurements show in the way of accuracy. If the bit is running out considerably, as sometimes happens on the first rough cut, the work may be reversed after the cut has gone half way through, and the bore be finished from the other end. Any eccentricity may be corrected by truing up the bore with a slightly larger bit. Four cuts are usually required to finish a bore—two rough and two fine ones.

(4) In boring out cylinders which are stepped and have two or more internal diameters, all work, except perhaps the first rough cut, as noted above, is done from the end where the diameter is largest, usually the breech. After the rough cut has been taken, the largest diameter is accurately bored out. A packed bit is then prepared with the forward end and tool set at the diameter of the smaller hole to be cut, while the after end is left at the larger diameter. This bit is run in and the smaller bore is started. The bit is then withdrawn and the bore is indicated and star gauged.

(5) In all boring, the bits are kept well lubricated by oil run into the bore.

315. Balance rod or indicator.—To ascertain whether a hole has been bored true with the line of dead centers, a simple device known as a *balance rod* or *indicator* is used. This device con-

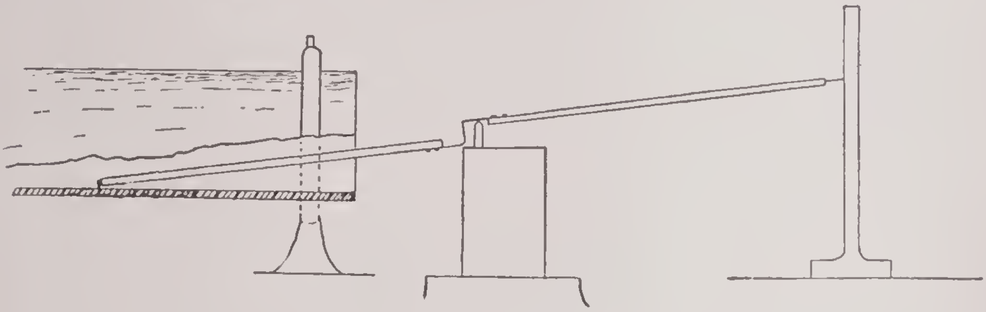


FIG. 56.—BALANCE-ROD, OR INDICATOR.

sists of two wooden rods joined together end-on by a right-angled strap of iron. One rod, the one which enters the bore, has a small roller on its end. The other rod holds a pointer. The rod is inserted in the bore and balanced on a knife edge under the iron strap, the roller resting on the bore. A vertical stand is placed so as to record the marking of the pointer. A zero point is first marked by the pointer, and then the work is slowly revolved. Should the hole be eccentric, the pointer will move up or down and serve as a means of indicating the amount of eccentricity of the bore at the point where the roller is. These indications are taken every two feet. A long forging that is being bored will be indicated about three different times during a cut, to see whether the bit is running true. Should the bit be running out, the centers are thrown and the bore is trued up with a slightly larger bit. After an accurate hole has once been bored there is little danger of the bit running out in succeeding cuts. (See Fig. 56.)

For guns which are set in lathes where there is not room to use this type of indicator, another one is used. This, as shown in the photograph (Fig. 3, Plate I), is mounted on the tool carriage at the end of the gun. A heavy, rigid beam carrying a small wheel on its end enters the bore, the wheel resting on the surface of the bore. The beam is supported on a knife-edge near its other end, and by a system of levers delivers its movement to a pointer traveling over a scale. A weight on the pointer rod is used to balance partly the beam. The allowable travel of the carriage between the breech of the gun and the fixed guide on the lathe for the dead center, is only a few feet; so, after indicating part of the bore, the beam is replaced by a longer one. This is continued until the entire bore has been gone over.

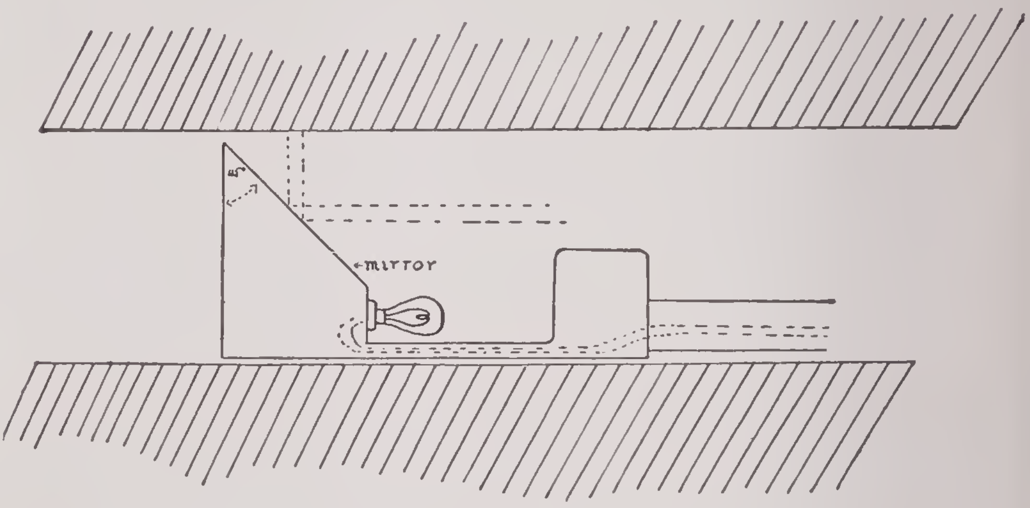


FIG. 57.—BORE-SEARCHER.

316. Bore searching.—(1) Every forging, when finish-bored, is bore searched, and all bore searching is done by officers. The bore is also inspected after each cut, by a foreman with an electric light.

(2) The *bore searcher* is simply a wooden frame, holding a mirror inclined 45° to the axis of the bore. Three incandescent electric lamps furnish the light, and a hood is provided on the frame to obscure the direct light from the observer. The bore searcher is moved slowly through the bore by a long wooden handle. About 90° of the bore is illuminated at once, and four lightings are required completely to search it.

(3) The bore is inspected for any discoloration, cracks, or streaks, or any flaws that may have developed in the boring; opera glasses or binoculars are used, if considered necessary, in inspecting long bores. If any flaws are noticed, they may be scratched with the *pricker,* a steel point mounted on a light wooden rod at right angles to it, to see that what appears to be a flaw is not merely a spot of dirt.

317. Star gauge.—(1) The *star gauge* (Fig. 58) is used to measure accurately the inner diameters of any long cylinder. This instrument is a graduated brass or steel tube, built in sections so as

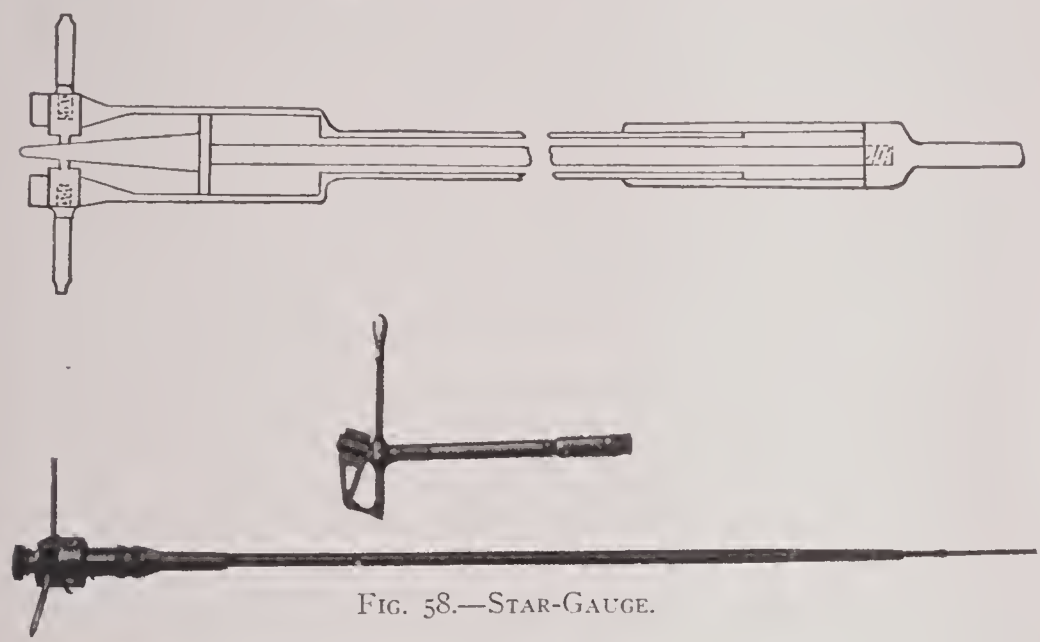


FIG. 58.—STAR-GAUGE.

to be adapted to any length of work. It carries a *head* and a *handle.*

(2) The head contains three sockets, 120° apart, pressed upon a coned rod by springs. Into these sockets are screwed points of lengths suitable to the work to be measured. The coned rod is simply the extension of a rigid steel rod passing through the tube and securing to the handle. Any forward movement of the handle moves the cone forward and causes the points to be pressed out a known amount, which is read from a scale on the tube and a vernier on the handle.

(3) The star gauge is always adjusted before use by trying the points on a ring of known diameter. A set of rings of different diameters is supplied with the instrument. By adjusting the posi-

tion of the handle the scale is made to read zero when all three points just touch the ring. In measuring the diameters of the bore the readings of the scale must be applied to the diameter of the test ring to get the correct diameters The bore, whether of forging or of gun, is star gauged at each inch of length and the powder chamber at each half-inch. The points are first set thus: ☮ and then a second series of readings is taken with the points reversed, thus: Ⓨ

(4) In star gauging the gun, after it has been rifled, guides are used on the head. These guides follow grooves and thus keep the points always on the same lands or in the same grooves. On the muzzles of all our guns the letter "S" will be found in four places. From the positions of this letter the lands and

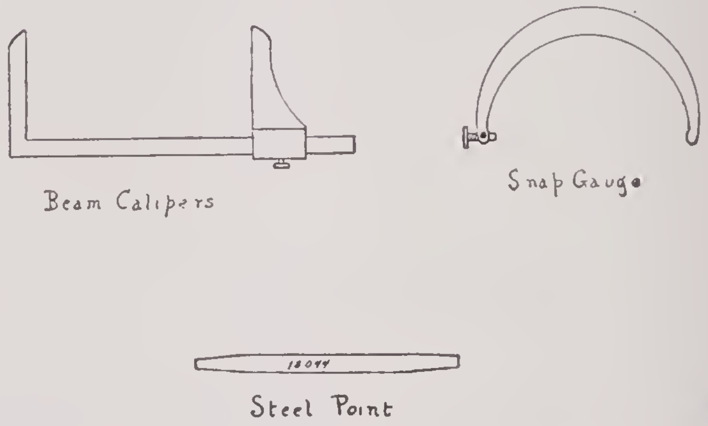


FIG. 59.—INSTRUMENTS FOR MEASUREMENT OF DIAMETERS.

grooves which were star gauged are known. Double readings are taken of both lands and grooves, the second reading being with the points reversed.

(5) The readings of the star gauge are correct to the .001 part of an inch. The record of every star gauging, whether of gun or of forgings, is kept on file.

318. Shrinkage.—The shrinkages for the different parts are prescribed by the Bureau of Ordnance. They are computed and are the same for all guns of a type if the material used in the different guns is of about the same strength. The different layers of the gun have different shrinkages, and the shrinkage in any one layer is not necessarily the same throughout.

319. Measurements.—(1) The figured dimensions on drawings are used. The rear face of the tube is taken as the origin for all measurements.

(2) In all machining the workman is furnished with the necessary gauges, graduated rods, and steel points for the dimensions on his drawings. All measurements originate in the measuring department, and all gauges are frequently referred there for verification.

(3) In general, diameters are given in thousandths of an inch and lengths in hundredths. Certain tolerances are allowed in machining, and these are never exceeded.

(4) Outside diameters are measured either with snap gauges or with beam calipers. Inside diameters, with steel points or the star gauge. (See Fig. 59.)

Building up the Gun.

320. Jacket.—(1) The B1 hoop or *jacket* is the first forging worked upon. A rough cut is first taken off the outside to remove spring, and then the forging is set for boring and bored out to exact dimensions. This usually requires two rough cuts and two finishing cuts with packed bits.

(2) The forging is faced off, inspected for flaws on the outside, and then removed from the lathe and bore searched, any flaws being noted. It is star gauged at each inch of length, the gauge being run through twice, as noted above. The length is divided into four parts by cuts on the outer surface; these distances are measured and the outer diameters are calipered. These divisions and diameters are again measured and calipered after assembling, to note what extension of diameter has been given the jacket, and to see if the longitudinal contraction has been uniform.

(3) The B2 hoop is at the same time prepared for assembling by the same processes of machining, inspecting, and star gauging. The shrinkage sheet for the tube is then made out as follows: To the internal diameters of the B1 and B2 hoops, as found by star gauging, are added the shrinkages assigned by the Bureau of Ordnance for each point. The resulting measurements are marked on a blue-print of the tube, giving the desired external diameter of the tube at each point. The tube is then machined.

321. Tube.—(1) After a rough cut has been taken from the outside of the tube, it is set for boring, and the bore is cut out to within .35 of an inch of finished diameter, two cuts with a packed bit being required.

(2) The tube is again set for turning, faced off true, and turned down to the dimensions given on the shrinkage sheet, the tolerance allowed being .001 of an inch only. It is inspected while in the lathe by an officer, who assures himself by numerous measurements that the shrinkage surface is of correct dimensions, and that no flaws exist in the metal. The tube is then removed from the lathe and bore searched and star gauged. It is now ready for assembling.

322. The shrinking pit.—(1) The tube is placed in the *shrinking pit* breech end down. The shrinking pit is a well of square section having two movable tables. On the lower table, and also

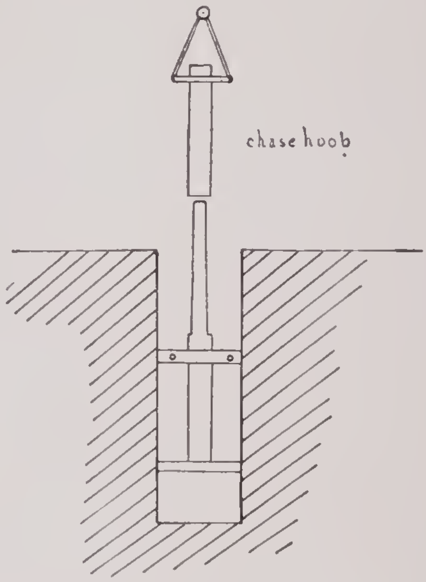


FIG. 60.—SHRINKING-PIT.

on the floor of the pit, are heavy mandrels which enter the bore of the tube; and by screws alongside of these the tube can be made perfectly vertical. When pieces are to be shrunk on from the breech end, the tube is held vertical by four adjusting screws in the upper table. For small guns the lower table is moved up to fit the length of work. Long pieces, as 12-inch 50-caliber or 14-inch tubes, rest directly on the floor of the pit. To keep the tube cool, water is pumped in at the bottom, rising to the top and flowing down again through a central pipe.

323. Heating furnaces.—(1) A heavy collar, carrying two trunnions to which the chains of the crane can be hooked, is bolted to the jacket, and it is lowered, breech end first, into a *hot-air*

SHRINKING ON 14-INCH CI HOOP.
A, Heating-Furnace (cover removed).

furnace. This furnace is a vertical cylinder, built in sections to suit the particular lengths of jackets, and is made of fire brick lagged with asbestos. Heat is absorbed from air which has been passed in pipes over petroleum burners. Large pipes lead from the air heater to each end of the furnace, and also, in a furnace now installed, to the middle. Air is passed in at the bottom and out at the top of the furnace, or vice versa, as needed to maintain a regular rise of temperature, as shown by electric pyrometers at the top, bottom, and middle. Hot air is admitted at the center to "boost" the heating at the exhaust end when desired. At *A,* Plate II, is shown a furnace with the top cover removed.

(2) For short hoops a shorter furnace is used, in which petroleum burners play into a space between brick walls, the gases and flame rising around the pieces to be heated. This causes deposits of soot on the hoops, but the furnace is only used for hoops so short that they can be easily swabbed out before assembling.

(3) In heating a gun for putting in a liner, it is difficult to get the required temperature in the heavy parts around the chamber; so an electric *booster* is used. This is a cylinder of fire brick, lagged with asbestos, and has resistance wires wound around on its inner surface. A 220-volt alternating current is used. A temperature of 1000° F. can be obtained with 30 kilowatts of current. There are two sections, each 50 inches long, which can be inserted in the hot-air furnace where they are most needed.

(4) Air heating is regular, and practically no local heating or warping occurs. Furthermore, the jacket is kept free from dirt. The heating takes place gradually, a large jacket requiring 30 hours to attain the desired temperature. Every precaution is taken to keep the heating uniform throughout, reversing the direction of flow of the hot air when necessary. The temperatures used depend on the amount of shrinkage assigned, and on the amount of clearance necessary for assembling. In small guns, as little as .005 inch is sometimes considered sufficient, but in all 14-inch work .025 inch clearance is desired, requiring the diameter of the hoop to be .05 inch greater than that of the part over which it goes. The coefficient of expansion of steel being .0000075 for 1° F., the necessary temperature is easily found.

(5) While the jacket is in the furnace, its diameter is measured by lowering steel cross-points into it. The lengths of these cross-

points are equal to the original diameter of the jacket plus the desired expansion.

(6) The 14-inch jacket is given a temperature of 725° F. at the breech end and 825° at the muzzle end, so as to insure its gripping first at the breech end.

324. First assemblage.—(1) When the jacket has received the desired expansion, it is hoisted out of the furnace, and tried for diameter with cross-points, previously checked. The bore is wiped out with a moist muslin sponge. The jacket is swung over the tube, centered by men with asbestos gloves, and lowered over the tube until it brings up at the proper point. It is guided down by the workmen and turned to prevent sticking and to assist the centering. When it is in place, a cold spray from one of the several rings of perforated pipe is turned on the part which it is desired to have grip first—in this case the breech end. Water is in the meantime circulated inside the tube. When the breech end is considered cooled enough to grip, other sprays are turned on, at intervals of one minute, and then the rings of perforated pipe are hoisted slowly up the jacket, spraying water and cooling it, so that when they reach the top, the whole jacket has gripped the tube. It is then allowed to finish cooling gradually. Plate II shows a 14-inch C1 hoop being lowered over the gun in the pit.

(2) Should the jacket "gall" or stick while being lowered, it is at once hoisted off and allowed to cool. The abrasions are filed off, and after being heated it is tried again.

(3) The tube has already been turned to proper size to receive the B2 hoop, so it is left in the shrinking pit, while the B2 hoop is heated. When proper temperature is obtained, the B2 hoop is shrunk on, water being applied to make it grip at the end nearest the breech, as was the case for the jacket.

(4) After the gun has cooled, it is removed from the pit. The jacket and hoop are measured on the marks previously scribed, to get their expansion in diameter, and longitudinal contraction, and the bore is star gauged. The internal measurements, showing contraction of the bore, serve as an efficient check on the shrinkage, and if the contractions do not correspond closely to those calculated, the question must be referred to the Bureau of Ordnance.

325. Successive assemblages.—(1) Each hoop is prepared for assemblage by having a rough cut taken from the outside to remove spring, then being bored out, bore searched and star gauged, after which the shrinkage sheets are made out as previously described.

(2) After the B1 and B2 hoops are assembled, the C1 hoop is prepared. The gun is placed in a lathe, and the outside of the B1 jacket and B2 hoop is turned down to the dimensions given on the shrinkage sheets, the gun is inspected, and placed in the shrinking pit. The C1 hoop is heated and shrunk on, water being applied to make it grip first at the breech end. When cool, the bore is star gauged and the compression is noted.

(3) The D1 and D2 hoops are now prepared for assembling, and the gun is placed in the lathe and turned down to the dimensions on their shrinkage sheets. The D1 hoop is shrunk on, and as soon as the gun is cool the D2 hoop is assembled. All these hoops go on over the muzzle end, and all are made to grip first at the end toward the breech.

(4) The D3 and C3 hoops being locking hoops, a different procedure must be followed in putting them on, as is seen from an inspection of the drawing. This procedure is as follows: The hoop D3 is rough turned and bored out to the finish dimensions. The shrinkage sheet is made out for the C2 hoop, and it is turned down. Then the C2 hoop is placed in the shrinking pit, end toward the breech up; the D3 hoop is heated in the short furnace, using the direct flame and gases of the oil burners, and is shrunk on. Great care must be taken in this operation to have the D3 hoop in exactly the right position on the C2 hoop, because if the shoulder on D3 did not enter accurately in the recess in C2, it would grip some of the metal too hard, crushing it, while other places would not be gripped at all. The assembled C2 and D3 hoops are star gauged to note compression, when cool, and are then placed in a lathe, and bored out to finish inside diameters. The shrinkage sheet is made out, and the partially assembled gun is placed in a lathe and turned down to receive the two hoops. They are then heated together, and shrunk on the gun, the same care being used to make the D3 hoop grip in the proper place on C1. In a similar manner, C3 is assembled on B3, and the two are assembled on the gun. After the final assemblage, the bore of the

gun is star gauged and the compression caused by assembling D1, D2, D3, C2, C3, and B3 is noted and checked up.

(5) The assemblage of the gun is now complete, and it is ready for the finish machining, rifling, etc.

Finishing the Gun.

326. (1) The assembled gun is now put in a lathe, muzzle end to the face plate, whose jaws grip on the extra metal purposely left for the bell muzzle. It is carefully centered, especially with regard to the bore, and then tested with the balance rod for spring. The centers are thrown to compensate for any spring or warping, and then the outside is turned down to within .02 inch of finished diameter. The balance rod is used as necessary to see that the spring is completely removed.

(2) The bore is now brought down to the finish diameters, two cuts with packed bits being required. The first cut brings the bore to .1 inch of finished diameter, the second to exact size. Great care is required in this operation to get the bore exactly true, and as close as possible to the finish dimensions.

(3) All finish boring for new guns is done from the breech end, so that if the bit runs out slightly in the final cut, the center of the muzzle may be thrown slightly and the muzzle turned concentric with the bore. In relined guns, the finish boring is done from the muzzle end.

327. Chambering.—(1) While the gun is in the lathe for boring, the chamber is bored out with a packed bit, and the compression slope is cut with a packed bit of the proper taper. This completes the chambering for guns with chambers whose diameters are the same from entrance to compression slope, as is the case in the 14-inch, and they are ready for rifling. Guns with narrow-neck chambers may also be rifled at this stage if desired, the chamber having been bored out to the diameter of the neck, or they may be sent to the chambering machine, where the chamber is finished by a special *chambering bar*. This has a bearing in the bore just forward of the chamber, and the tool is fed along by gearing working inside the bar. To obtain the proper slopes the tool is fed in and out by a lug working in a slot in a key which extends along the bar.

(2) In guns using cartridge cases, the chamber is cut to the required form by packed bits, the finishing bit carrying a long tool set to the correct taper. The chamber is inspected by fitting in it a dummy case of the exact form desired.

328. Bore searching and star gauging.—(1) The gun is now carefully bore searched for any defects that may have appeared in finish boring or chambering, or for any rough spots or tool marks, etc.

(2) The bore and chamber are then star gauged at each inch of length, except that the slope of the chamber is not star gauged, as a slight error in the position of the gauge would make a large difference in the reading, and the record would have no value.

329. Rifling.—(1) The *rifling,* which consists of cutting spiral grooves in the surface of the bore from the compression slope to

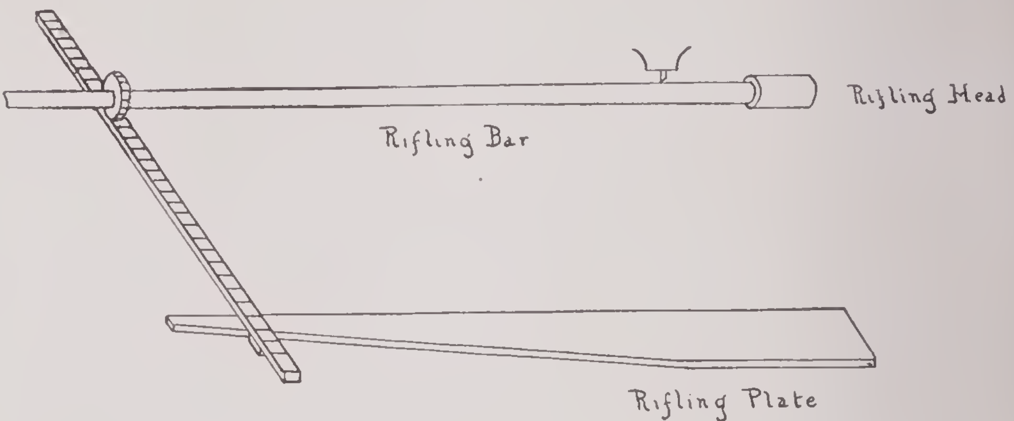


FIG. 61.

the muzzle, is done, as noted, either before or after the final chambering.

(2) Before rifling a gun of a new type, it is necessary to construct a *rifling plate,* and from it a *rifling bar.* The following is the procedure: A drawing is made of the curve of rifling in the bore developed on a plane surface, and an iron template is constructed with one edge straight, while the other is cut to the developed curve of the rifling. For uniform twist, this is a straight line at a constant angle to the straight side, but for increasing twist it is a curve. This plate is secured to one side of the lathe used for cutting rifling bars, and has pressed against its curved side a roller carried in an arm extending across the bed plate. The top of this arm is a rack which, through a series of pinions, drives the

FIG. 1.—RIFLING-HEAD.

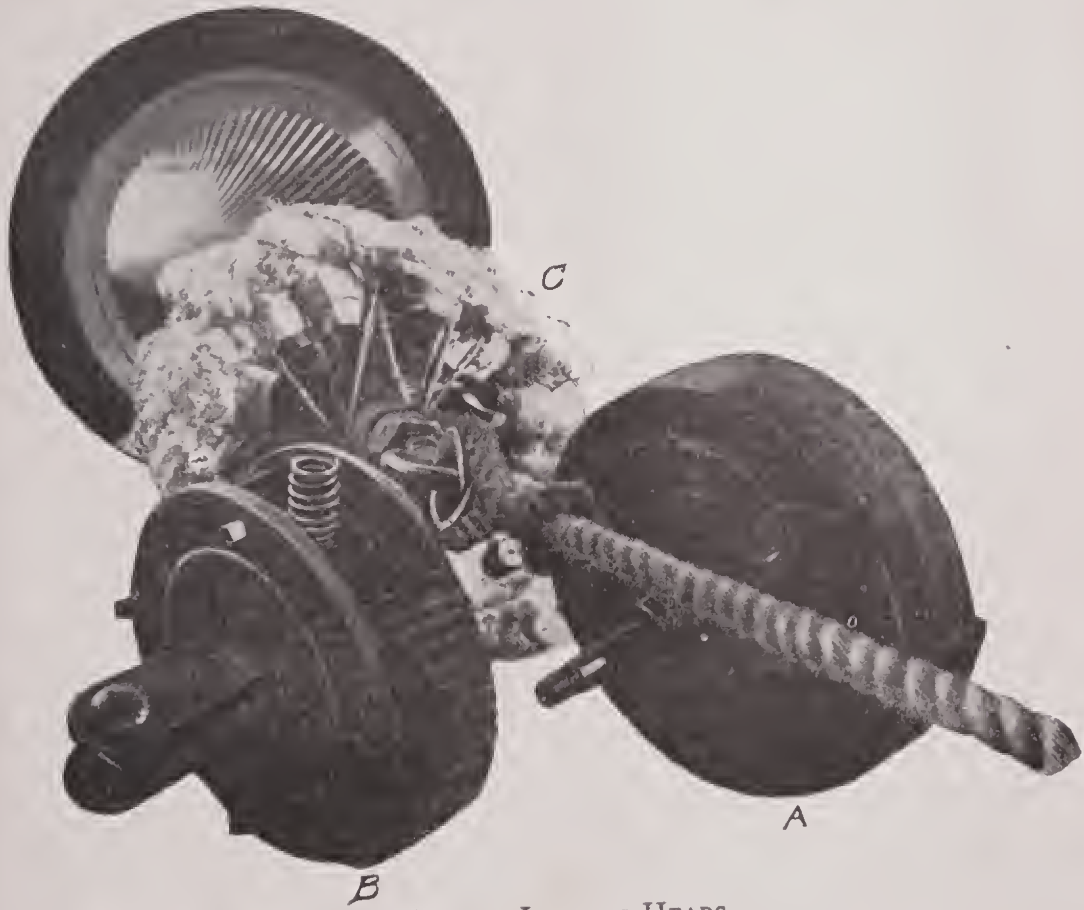


FIG. 2.—LAPPING-HEADS.

head carrying the rifling bar. As the rifling bar is fed along, it is turned the necessary amount, so that the rigidly held tool against which it is fed makes on its surface a curve like that desired in the rifling. A heavy weight sliding between two uprights on the carriage, suspended from a strap wound round a wheel on the head, serves to keep the roller always tightly pressed against the edge of the template.

The slot cut in the surface of the rifling bar is about .5 inch wide and .5 inch deep. To cut grooves wider at the breech end than at the muzzle, as is done with practically all guns, a secondary slot must be cut in the rifling bar, in the same manner. This is like the first, but differs from it enough to widen the grooves the necessary amount.

(3) All rifling is done from the muzzle end. To cut the grooves, the rifling head is keyed in the socket in the end of the rifling bar, and carefully centered with the gun. This head (Fig. 1, Plate III) is a hollow steel cylinder, slightly smaller than the bore of the gun, holding eight cutting tools arranged in pairs 90° apart.

By means of wedges controlled by screws on the front face of the cylinder, the tools can be set out separately, or together, a graduated collar surrounding the central screw giving a means of reading the amount when all are moved together. For large guns the rifling head is capable of rotation on its shaft. While grooves are being cut, it is held rigidly in position on the rifling bar by pins engaging in holes in a ring on its after end, but when one set of grooves is finished the pins are withdrawn and the head moved to the position for a new cut. For small guns, the rifling head cannot be turned on its shaft, but the gun itself is mounted in a graduated collar which is turned as necessary, a pointer attached to the lathe serving to indicate the amount of movement.

The head being mounted, and the tools set for the first cut, the rifling bar is fed into the gun. A lug on its forward steady-rest engages in the slot cut on the bar, revolving the bar as it is fed forward and causing the head to cut spiral grooves of the desired curvature in the bore of the gun. Very small cuts are taken, to keep the metal from jamming in front of the tools, so that from 15 to 30 cuts are necessary for one set of grooves. After all grooves have been cut, the lug on the steady-rest is engaged in the

secondary slot in the rifling bar, and the work is gone over, giving each groove the required enlargement toward the breech.

The cutters are kept well lubricated with oil fed in the breech during the entire operation. A semi-circular brass sleeve is pushed into the bore, by proper mechanism, at half the speed of the head, and helps support the shaft.

(4) After rifling, the lands are star gauged at every inch of length, and the grooves, for the first eight calibers from the origin of rifling, are star gauged at every half-inch of length.

330. During the World War a number of rifling heads were developed, operating on the principle of a *broach*. These are provided with a series of hardened steel disks, with cutters all around the periphery capable of taking a cut from 0.001 to 0.002 inch deep. Each disk in the series cuts from 0.001 to 0.002 inch deeper than the disk just preceding it, so that by using the whole series the rifling grooves can be cut to the required depth. When a gun is to be rifled, the first disk or broach in the series is secured to the forward end of the rifling head. The rifling bar is then fed into the gun from the muzzle end, the broach cutting grooves 0.002 inch deep all around the inside of the bore. At the breech end of the gun the broach is removed and the rifling head drawn back through the gun to the muzzle. There another disk is attached to the head, this being the second broach in the series, and the operation is then repeated. The second cut serves to deepen by 0.002 inch the grooves cut by the first broach, and so on until the whole series has been used and the rifling grooves are of the proper depth. For guns of intermediate caliber and below, sufficient cutters are provided on the periphery of the broach to cut all grooves at one time. In the case of major caliber guns there are usually cutters enough for one-half the grooves. Thus a 16-inch gun has 96 grooves, while the broach used in rifling it is provided with 48 cutters. The operation of rifling the gun consists, therefore, of two parts, but it is still much quicker than can be accomplished with the older style of rifling head.

331. Finish turning.—After rifling, if the gun has been chambered, it is returned to the lathe, where the outside is turned down to finished diameters, the bell muzzle is finished, and the gun is faced off to the correct length. In guns which are hooped to the muzzle, the tube projects about .25 inch beyond the end of the

hoop. During the turning, any opening of outside joints is closed by "rolling"—*i. e.,* forcing a tool carrying a small wheel against it as the gun is revolved.

332. Determination of droop.—In order that the gun, when finally mounted, may be in the most advantageous position, it is now tested to ascertain the point of least droop. It is centered in a lathe, the breech end is gripped by the jaws of the face plate, and the point where the gun will be supported by the trunnions is held by steady-rests. The gun is now revolved, and by means of a small spring indicator held against the muzzle, the points of greatest and least comparative droop are determined. These are marked, and then the absolute droop at these two points and two other points diametrically opposite is measured, using the tail stock of the lathe for reference. From the information thus obtained, the position of the gun in which it shows least droop is noted, and the top of the breech is marked to show where to start the thread for the screw-box collar.

333. Chasing thread for screw-box collar.—(1) In all guns from 4 to 14 inches, inclusive, the screw-box threads are cut in a separate collar which screws into the breech of the gun—in some cases into threads cut in the jacket; in others, as the 14-inch, into threads cut in the C1 and D1 hoops.

(2) The gun is put in the lathe with muzzle end to the face plate, and the after ends of the A tube and B1 jacket are faced off true as one surface, both extending the same distance to the rear. The C1 hoop is then faced off at an exact distance in rear of the end of the A tube and B1 jacket, determined by an accurate gauge. Finally, the D1 hoop is faced off at an accurately gauged distance in rear of the end of the C1 hoop.

(3) The C1 and D1 hoops are then bored out to exact diameters, using a tool mounted on a head and fed in by its carriage while the work revolves. These diameters having been checked up by steel points, a slot the depth of the thread to be chased, usually .25 inch, is cut in D1 where it joins C1, and in the C1 hoop where it joins B1, to allow clearance for the tool which is to chase the thread.

(4) The thread is then chased, starting it at the point determined by the droop measurements, so that when the screw-box collar is screwed home the right part of the gun will be up.

The thread in the D1 hoop is first chased, and then that in C1, the latter being an exact continuation of the former. The thread is tested for accuracy with gauges, which must fit the threads in both C1 and D1 hoops at the same time.

(5) The screw-box collar, prepared as noted in the manufacture of breech mechanisms, is fitted to the gun while it is still in the lathe, so that any further work necessary for fitting may be done at once. This work must be very accurate, as the collar must take up firmly against both the ends of the tube and jacket, and the D1 hoop at the same time. In the fit with the end of the C1 hoop, .001 or .002 inch clearance is tolerated.

(6) The breech is now marked for holes for heavy countersunk screws to keep the collar from turning, and these are drilled and threaded. The screws are put in place and the collar is secured.

334. Lapping.—(1) The bore of the gun is now lapped to remove all burrs, etc. First a head (*A*, Fig. 2, Plate III) holding four segments of wood covered with emery cloth, held out against the bore by spiral springs, is run through, while emery flour and water are put in with a swab. This smooths the lands. For the grooves a similar head is used, but with segments of lead cut to fit the grooves (*B*, Fig. 2, Plate III). Finally, a head covered with burlap and waste is run through to clean out the bore thoroughly (*C*, Fig. 2, Plate III). Clean waste is put on this head and tied in place with twine, as required. The heads are drawn back and forth through the gun by a machine which reverses itself at the end of the travel each way.

(2) Though not connected with the subject of gun construction, it is well to mention here the question of lapping guns aboard ship. Quite frequently the bores of guns in service become constricted to such an extent that a bore plug gauge of the same diameter as the projectiles to be fired cannot be pulled through the guns. Ordinarily this constriction is due to an accumulation of copper from the shell rotating bands, and as such is not considered especially harmful or dangerous to the gun. As will be seen later, however, under the subject of relining guns, this constriction is sometimes caused by a shoulder on the liner over-riding the corresponding shoulder on the tube, in which case the bore of the gun is actually contracted to a diameter less than that of the shell, making it dangerous to fire the gun. In this case it becomes necessary to remove the obstruction to the passage of the bore

gauge by lapping the tops of the lands. For this purpose it was customary for ships to construct their own lapping heads, usually of blocks of wood set outward by springs against the bore of the gun, the whole head being then covered with emery cloth similar to *A*, Fig. 2, Plate III. A line was attached to each end of the lapping head and drawn back and forth by members of the guns crew. Care had to be taken not to draw the lapping head beyond the actual limits of the constriction, as shown by measurement of the points where the bore gauge stuck, in order to avoid unnecessary wear on the gun. Such lapping heads were more or less crude in construction, and when possible the work was done at navy yards. The latter are now provided with the necessary equipment and measures are being taken also to supply lapping heads afloat.

335. **Fitting breech mechanism.**—The necessary holes for fitting the breech mechanism are drilled, the hinge plate or hinge bolt is put in place, and the breech block is fitted. Previously to fitting the breech block, it is fitted in a dummy gun, so that when actual fitting takes place the work will not be so difficult. There is always considerable hand work in fitting every breech mechanism. When the fitting is complete, the block is marked with the number of the gun.

336. **Milling keyway.**—Whenever convenient during the final finishing work on the gun, the keyway on its top, to take the key which keeps the gun from turning in its slide, is cut. A special portable milling machine operated by an electric motor is strapped on top the gun for this purpose.

NOTE.—The processes of finishing, from rifling on, are not carried out in any regular order; the gun is routed through the shops as the machines are ready to receive it, the only requirement being that it must be finish-bored, finish-turned on the outside, and measured for droop before the threads for the screw-box collar are chased. In some cases the breech-mechanism has been fitted before the gun was rifled, while in others the rifling has been done before the final chambering.

337. **Putting on yoke.**—The yoke, of forged or cast steel, may be put on in several ways. In the smaller guns it is often screwed or shrunk on, but in most large caliber guns, including the 14-inch, it is put on over the breech and abuts against a shoulder on the D1 hoop which prevents its forward movement. Just in rear of the yoke an annular slot is turned in the gun, in which two sections,

each about 60°, of a steel ring are secured by countersunk screws, one at the top and one at the bottom of the gun, to prevent backward movement of the yoke. This annular slot for the backing ring is cut whenever convenient during the finishing processes of the gun. The yoke is now considered part of the gun.

338. Balancing for center of gravity.—The gun with breech mechanism, with a projectile and charge, is balanced on knife edges to find the center of gravity. This is done for only one gun of a type. The center of gravity of each gun is previously computed, in addition, for convenience in designing.

339. Weight.—The gun, with breech mechanism, is now weighed, and this weight is marked on the face of the breech. The weight of the breech mechanism is also marked on the block, but this is included in the weight of the gun.

340. Final inspection and marking.—The gun is now finally inspected, the dimensions are verified, the breech mechanism is tested, etc., after which the gun is marked according to the standard marking, which gives place of manufacture, year, mark, number, and weight of the gun, and initials of superintendent and inspecting officer.

The gun is then fitted to the slide and as much of its mount as may be necessary, and is sent to the Naval Proving Ground for proof firing. After it has been proved, it is returned to the gun factory and, if satisfactory on proof, is relapped, bore searched, star gauged, and issued to the service. If unsatisfactory on proof, the defects noted are remedied if possible, and the gun is returned for re-proof.

Re-lining.

341. When a gun has fired a considerable number of rounds, the actual number depending on the caliber of the gun and its designed muzzle velocity, the bore becomes eroded to such an extent that the gun gives undue dispersion. It then becomes necessary to bore out the gun, insert a liner, and then rifle and chamber the liner. Until recently cylindrical liners were used, but now conical liners, tapering toward the muzzle end, are inserted. It has also become customary, since the introduction of conical liners, to build guns of 5-inch caliber and above with a liner already inserted. When it becomes necessary to re-line, the

original liner is simply pulled out from the breech end of the gun and a new one put in its place.

The operation of lining a gun consists in the main of preparing the gun to receive the liner, machining and shrinking in the liner, and finishing the gun. If the gun has previously been unlined, it is necessary to bore out the tube sufficiently to receive the liner. This is done by placing the gun in the lathe and roughing out the bore with packed bits, followed by a final boring with a number of tapered bits. All boring is done from the breech, and the taper is .003 inch to the inch, the diameter decreasing from breech to muzzle.

The rough boring is done similarly to that described in paragraph 314. The cuts are made successively from the breech, and there are one, two, or three shoulders, so that, as far as possible, the amount of metal to be removed by the tapered bits may be reduced. The latest practice is to confine the number of shoulders to one or possibly two, located well back near the origin of rifling. It was found that, with shoulders out toward the muzzle, the mandrelling effect of the projectile passing down the bore was liable to cause the relatively thin-walled liner to "ride up" on the shoulders on the tube, thereby producing a constriction in the bore of the gun.

After roughing out with packed bits, the bore is smooth bored with tapered bits. The bit for the muzzle section is first run through to the muzzle. Then the next bit in rear is run through to within a few inches of the beginning of the cut made by the muzzle bit, and then this bit is withdrawn, the two cuts are star gauged, and the bit is replaced and worked carefully up to the line between the two cuts, taking care that no shoulder or ridge is left. This merging of the one cut into the other is known as "*blending*"; the forward end of each bit is made with the diameter for several inches coincident with that of the last few inches of the previous bit, so that the "blend" may be made smooth by overlapping the cuts. The several bits are put on in turn, each cut being blended into the previous one, until the entire length of the gun is bored. The feed is very slow, about 6 to 7 inches an hour.

After the boring is completed, the bore is star gauged throughout its length, and a shrinkage sheet for the liner is made out. The shrinkage is very small, only from .005 to .006 inch for 12-inch guns, and less for smaller. This shrinkage is enough to

hold the liner in place, without undue strain thereon, since, in the calculations of the gun, the liner is not considered as an additional layer for giving elastic strength by shrinkage. The liner is rough turned from the forging, bored out to within .65 inch of its final diameter, and then replaced in the lathe for turning. With the shrinkage sheet prepared for it, it is finish-turned, using a head which feeds the tool slowly along, and is then smoothed down by filing any rough spots. It is then coated with a mixture of graphite and machine oil. (It may be left dry, but this coating prevents "galling" in shrinking.)

The gun is placed, muzzle down, in the furnace, and is heated thoroughly to a temperature of 400° to 500° F. A brass plug is then screwed into threads cut in the muzzle of the liner (to keep the hot air in the gun from getting inside and expanding the liner as it is inserted), and a steel lifting plug is screwed into the breech. Into this lifting plug are shackled the crane falls. A rope sling is placed about the muzzle end of the liner and the whole is hoisted, the liner in a horizontal position, and then the sling is slacked until the liner is hanging vertically, when the sling is removed. The crane is then moved until the liner is hanging directly over the gun. The heat is turned off and the lid of the furnace is removed. The vertical position of the liner is verified by a spirit level, and its position over the center of the gun is tested by placing a wooden batten against the liner at four quadrantal points, and noting the position, on the breech of the gun, of a pointer attached to the batten.

The liner is slowly lowered until its muzzle is within the breech of the gun. It is then lowered rapidly, checking as it is about to pass each shoulder, until in place. The crane falls are unhooked, and a heavy iron head is put over the liner, a hydraulic jack is placed above this, and over all a heavy yoke which takes under nuts on the tops of two heavy tie-rods passing down through the sides of the furnace. Pressure is put on the jack, and the liner is held firmly in the gun, preventing its backing out on cooling. The gun is then allowed to cool, no water being sprayed on, but one section of the furnace being removed to allow free access of air. After four or five hours, or when it is considered that the liner has "set," the jack is removed, and the lifting block is unscrewed and removed.

After the gun is thoroughly cooled it is removed, and then chambered, rifled, and finished as described above.

In fitting a cylindrical liner the process is similar, but, after the rough boring, smooth boring is done by straight packed bits instead of the tapered bits, and one bit is sufficient for each section between shoulders. The cylindrical liners are generally thicker than the tapered, and the shrinkages greater.

342. Some guns have been built with liners in them originally, as is the case of the 12-inch, Mark VII. These liners are cylindrical, and fit smoothly, without shrinkage, inside the tube. The processes of boring and turning the tube and liner are similar, respectively, to those of fitting a cylindrical liner to an old gun. In assembling, the tube is heated to 500°, and lowered over the liner. On cooling, it makes a snug fit with the liner, and the gun is then assembled complete on the lined tube, as above described. The great objection to cylindrical liners is that they may not be readily removed when they are worn out, but must be bored out, thus slowly cutting away all the metal of the liner, with great loss of time and labor. The replacement of conical liners, however, is very simple. The gun is placed in the shrinking pit and heated to about 500° F. The cold water is turned through the liner. As the liner cools, it contracts, and may be allowed to fall out (gun being in the pit with muzzle up, and blocked several inches off the bottom) or may be pulled out by the crane (gun being breech up).

Gun Construction by Radial Expansion.

343. In the method of gun construction just described, the necessary tangential strength is obtained by shrinking one or more hoops over the tube, thus placing the metal in a condition of initial strain.

Another method is now being employed to a certain extent by the navy, known as the "Radial Expansion Method of Gun Construction."

The basis of this method of gun construction is the application of hydraulic or other pressure to the interior of the gun tube, by which the metal of the gun is cold stretched beyond its elastic limit, acquiring a permanent set. Metal which has thus been stretched acquires a new elastic limit greater than the original elastic strength of the metal, depending upon the amount of permanent elongation.

344. It has been known for more than 50 years that when a piece of steel is stretched beyond its elastic limit, thus acquiring a permanent stretch, there is imparted to it at the same time a new elastic limit greater than the original elastic limit of the metal, depending on the amount of permanent elongation produced.

Numerous and extensive experimentations have been carried out to ascertain the laws of this "Special Elasticity," and one of the results established is that the special elasticity, by gradual stretching in the above way, may be increased so as to practically coincide with the ultimate strength of the metal.

345. Along with these experiments were conducted others for determining the effect of cold stretching of hollow cylinders by the application of internal pressure. It has been only within the last 20 years or more that this process has been applied to steel, although certain experiments performed in 1874 established the fact that the elastic limit of steel obeyed the same general laws as earlier metals experimented with, and this process could be applied with great advantage to the hooping of built-up guns.

346. The convincing part of the process is that upon gradual application of internal hydraulic pressure the metal of the walls of the gun begin to "flow" upon reaching a pressure of from 36,000 to 60,000 pounds, the theoretical elastic strength of the gun, depending on the metal.

For instance, a nickel-steel tube which was shown on test to have an elastic limit of 60,000 pounds per square inch was subjected to hydraulic pressure on the interior amounting to 107,000 pounds per square inch. The external diameters of the gun continually expanding indicated a continuous flow of the metal beyond the elastic limit. At this point the pressure was released, and the exterior diameters returned toward their original value to a point which gave the permanent set of the metal. The permanent increase in the interior diameter was about 6 per cent to 8 per cent. After a mild heat treatment the new elastic limit of the material was determined to be approximately 110,000 pounds per square inch.

347. Whatever theory there may be concerning this method of gun construction, there is no doubt whatever that the elastic strength of the gun under experimentation had been raised from 60,000 to about 110,000 pounds per square inch, an increase of

80 per cent over its original value, showing the remarkable effect of the process on the elastic limit of the metal thus treated.

348. A further remarkable feature connected with this process is the condition of the initial strains in the metal walls of the tube as a result of cold stretching. Specimen rings cut from the waste metal at muzzle and breech show that the theoretical state of initial strains, shown by the theory of the process, exist in fact. The outer ring shows an initial strain of tension, while the inner ring shows a state of compression, the intervening hoops showing a gradual change through a neutral axis between these two extremes, which is the ideal condition for the walls of a gun. It is a condition, or an effect which the French have designated "*auto-frettage,*" literally "auto-hooping." The method of treatment they call "*écrouissage,*" meaning "hard hammered." It accomplishes, with more uniform results, the same effect produced by shrinking hoops on a built-up gun.

349. It has thus been practically and most thoroughly demonstrated that if a homogeneous metal tube is submitted to progressively increasing interior pressures its different concentric layers will take on successively permanent deformations, starting from the innermost layer. The layers thus deformed under pressure will remain in a deformed state after the removal of the load; in preventing the return of the outer layers to their original position the inner layers remain strained when they themselves, due to reaction, are contracted. The tube itself has acquired, in being deformed, the ideal composition of uniform auto-hooping, in which all the layers are equally affected as regards resistance.

In other words, the gun is made in one piece, or as it is called of "monoblock construction."

350. From a theoretical standpoint, there is no reason why this process may not be extended to the construction of the 16-inch 50-caliber gun, with all the advantages which it has shown for guns which may be constructed in a single piece. The mere question of size ought not to be a deterrent for the application of the process to these larger caliber guns. The formulas clearly indicate that it is not a question of size of diameter, but merely a ratio of external and internal diameters.

351. For the manufacture of guns by the radial expansion method the special equipment necessary consists of a pump, an "intensifier," a system of piping capable of withstanding high

pressures, and a suitable means for closing the ends of the forging that is to be stretched. The gun forging, bored out to a diameter somewhat less than the finished size desired, is successively stressed beyond its elastic limit, and careful measurements taken to ascertain the deformation produced. A mild heat treatment follows, which has the effect of "ageing" the metal and making permanent the increased elastic strength acquired by the stretching. The forging is then ready for finish boring, turning, and rifling as already described for built-up guns.

352. The advantages of this method are:

(a) Much lighter gun as compared with a gun of the same caliber produced by the old method.

(b) Less machine work, because of fewer surfaces to bore and turn.

(c) Less labor required in manufacture. (Less number of forgings to make and transport.)

(d) Cheaper and quicker gun construction, and hence increased output.

353. The only limiting feature of this method of gun construction appears to be the thickness of gun forging that can be depended upon as sound and free from defects.

354. So far only guns of intermediate caliber have been made by the radial expansion method. A 4-inch gun constructed by this process has been fired up to 464 rounds, and the life of the gun has not been reached. The velocity has been reduced by 100 foot-seconds, and the bore shows some wear, and slight increase in diameter. This gun was fired in comparison with the navy standard 4-inch gun, and has shown itself the equal of the standard gun in every way.

Inspections—Gun Structure.

355. The inspections pursued in the course of the manufacture and assemblage of the gun itself—disregarding the breech mechanism—have been noted as they occur in the progress of the work. They may be summarized, for reference, as follows:

(1) **Inspections by officers.**—The inspection officer in charge of major caliber guns is in general responsible for all work on the guns, and his initials are stamped on the breech of each gun. His duties, aside from general supervision, are:

(a) The bore searching of all forgings after rough boring, and the checking up of marks put on them by the steel works.

(b) All bore searching of finished or unfinished pieces, whenever noted in the description of manufacture. The officer also signs the statement in the star-gauge record book, giving date of inspection and any defects found.

(c) The checking up of the measurements marked on each shrinkage sheet with the star-gauge readings, and the checking of the measurement of the external diameter of the male part, when the finish turning is completed, to see that it conforms to the shrinkage sheet.

(2) **Inspections by workmen.**—During the progress of the work, measurements are taken by the workmen as often as necessary to insure accuracy. For all work, except turning conical liners, the men are furnished with steel points of the exact length of the desired diameters. These points are prepared in the tool shop, and are checked up on the special measuring machine in the gun-shop office. They are either used directly for measuring or are used in setting snap or beam calipers. For conical liners, the diameters are taken with snap calipers fitted with micrometer gauges. These gauges, as received from the manufacturer, are calibrated on points previously checked by the measuring machine, so that all measurements refer to this machine.

All internal diameters are measured by the star gauge, as noted. The rings for setting this gauge are checked by points calibrated on the measuring machine.

All fillets, screw threads, and curves, such as the bell muzzle, are tested during turning by profile gauges, made in the tool shop and issued to the workmen.

To measure the distances between surfaces, such as the rear faces of the tube and hoops, right-angled gauges which bear on one surface and have a leg which should just extend to the other are used. The clearance between this leg and the surface it should touch is tested in accurate work with feelers or cigarette papers. If the paper can just be pulled out without tearing, the clearance is .001 inch; while if it is held firmly, the clearance is not more than half that amount.

As each job is finished by the workman it is inspected by a responsible leading man or quarterman, using the appropriate gauges and steel points

CHAPTER X.

NAVAL GUN MOUNTS.

Nomenclature of Gun Mounts.

356. The mount.—The entire system interposed between the gun and the structure of the ship which serves to support the gun, secures it to the ship's structure, and provides for its elevation, train, recoil, and counter-recoil, is known as the mount.

357. The mount consists of the following parts: (1) stand, (2) carriage, and (3) slide.

The parts are defined as follows: (See Plates I and II.)

(1) **The stand** is that part of the mount which is secured to the structure of the ship, and in or upon which the carriage rests and is moved in train.

(2) **The carriage** is that part of the mount, supported by the stand, and which in turn supports the slide. To it are secured the trunnion seats, and in the case of pedestal mounts, the elevating and training gear.

(3) **The slide** is that part of the mount that supports the gun. The slide forms the sleeve through which the gun moves in recoil. The trunnions are secured to it and form an integral part.

NOTE.—Stands may be "pivot-stands," "cage stands," "rail sockets," "port-sill sockets," "boat stands," "pillar stands," "field-carriages," or any of numerous other special types.

358. Type names, such as "turret," "pedestal," "port sill," "military top," "rail," "boat," "field," etc., are sufficiently descriptive of a mount, and the names of the several parts may be used without modifying words.

The term pedestal mount is self-explanatory. The 3-inch, 4-inch, 5-inch, 6-inch mounts, and smaller mounts, are of this type.

Definitions—Discussion.

359. The principal requirements of a modern gun mount are: (1) Safety under all conditions, which necessitates proper design and requisite strength of materials, so that the mount will perform its function with the least danger to the personnel operating it;

(2) rapidity, ease, and smoothness of operation; (3) facility of adjustment; (4) simplicity and reliability; (5) gradual absorption of the shock of recoil and its dispersion over a sufficient area of the ship to prevent injury to the ship's structure; (6) accurate and reliable control of power, either hand or motor power.

360. All modern naval gun mountings are now designed to have an arc of elevation as follows: Turret guns, 40° elevation, 5° depression; broadside guns, 20° elevation, 10° depression. The train is usually limited only by the ship's structure and the location of the mount in the ship.

361. Mounts are conveniently divided into classes according to the kind of recoil mechanism used. These classes are (1) hydraulic-recoil spring-return mounts, (2) hydraulic-recoil spring-pneumatic-return mounts, (3) hydraulic-recoil pneumatic-return mounts, (4) hydraulic-recoil hydraulic-return mounts. In all recoil mounts, means are afforded for returning the gun to battery, *i. e.,* its initial position; this mechanism also assists to a limited extent in checking the recoil of the gun. The gun recoils in the line of fire. In all but the smaller mounts, buffers of some form are provided for cushioning the counter-recoil.

362. **A hydraulic-recoil spring-return mount** is one in which the recoil is checked by the by-passing of the liquid contained in the hydraulic cylinders from one side of the piston to the other during recoil, and the gun is returned to its battery position by springs.

363. **A hydraulic-recoil spring-pneumatic-return mount** is one in which the recoil is checked by the by-passing of the liquid contained in the hydraulic cylinders from one side of the piston to the other during recoil, and the gun is returned to its battery position by combined action of springs and compressed air.

NOTE.—This type of recoil mechanism was adopted when the elevation of the turret guns was increased from 20° to 30°. Later, when the angle of elevation was increased to 40° the springs were entirely abandoned, and compressed air used.

364. **A hydraulic-recoil pneumatic-return mount** is one in which the recoil is checked by the by-passing of the liquid contained in the hydraulic cylinders from one side of the piston to the other during recoil, and the gun is returned to its battery position by compressed air.

365. A hydraulic-recoil hydraulic-return mount is one in which the recoil is checked by the by-passing of the liquid contained in the hydraulic cylinders from one side of the piston to the other during recoil, and the gun is returned to its battery position by hydraulic pressure. This type of recoil mechanism has been consistently adhered to by the British Navy for their turrets. There are none of these mounts on vessels now in commission in the U. S. Navy.

366. A field mount, as used in the U. S. Navy, is one intended for shore use, and consists essentially of an axle mounted on two wheels, bearing a trail piece with a small trail wheel and a socket, to which is secured the gun mount proper. Except for machine guns, which have non-recoil mounts, hydraulic-recoil spring-return mounts are used. Train is effected mainly by swinging the whole mount on its wheels. In addition to the train thus provided, a limited amount of train of the carriage on the trail is provided on recent mounts. The elevating gear is fitted to the non-recoiling part of the mount. The general navy method is to carry ammuntion on the gun mount, as a " limber " hooped to the trail of the mount is too heavy to be dragged by men.

367. A turret mount is one in which heavy guns are mounted in an armored structure, which is revolved on rollers by suitable machinery, the guns being elevated independently of the structure.

368. The elevating gear, hand or power, is the machinery secured to the carriage which elevates or depresses the gun. The weight of the gun, powder charge, projectile, and other parts supported by the trunnions, are balanced at the trunnions. On firing, the gun moves to the rear, thereby disturbing this balance, and throwing extra forces on the elevating gear. (See Plates I and II.)

Metals Used in Gun Mounts.

369. The metals used for naval gun mountings are cast steel, forged steel, and special bronzes. Cast iron is not used. Cast steel is used for the principle strength members, such as the carriage, slide and stand, and also for the larger castings of the elevating and training gear. Bronze is used for all bearings and bushings where moving parts are of steel. Bronze is also used for the smaller castings, where the use of cast steel is impracticable,

on account of the difficulties of casting, and for all metal parts coming in contact with the powder.

General Description.

370. The following is a description of a typical broadside gun mount:

The *slide* (Fig. 2, Plate I) is a cylindrical steel casting fitted with a front and rear liner, in which the gun barrel slides in recoil. Cast solidly on the slide are two *trunnion* (Fig. 2, Plate I) bosses which support the slide and gun in the carriage. Beneath the slide and cast integrally with it are two circular brackets that support the *recoil cylinders* (Fig. 2, Plate I). Between the recoil cylinder brackets, at the forward end of the slide, is a pad to which is fixed the adjustable *elevating arc* (Fig. 3, Plate I). Recoil is checked by means of the combined action of the recoil cylinders and *counter-recoil springs.* Lugs are provided on the slide for the sight and other accessory apparatus.

The two arms of the carriage, which support the slide trunnions, are cast solidly with the hollow base and terminate in seats for the *cap squares* and *frictionless bearings.* Elevation is accomplished through a two-hand drive mounted on the left-hand side of the carriage and functioning through bevel gears and a worm to the *elevating pinion,* which meshes with the elevating arc. Brackets are bolted to the side of the carriage to support this mechanism. The arc of elevation is from 10° below horizontal to 20° above. All mounts are fitted with *firing keys* for electrical firing. Percussion firing on some mounts is accomplished by means of a hand lever mounted on the left-hand side of the carriage. It functions through a series of levers and telescopic shafts to the gear on the breech mechanism. A foot-firing gear is being fitted to some of the recent mounts.

The *gun carriage* is trained by means of a two-hand mechanism carried on brackets on the right-hand carriage arm, operating through bevel gears to a worm meshing with the *training circle,* which is bolted to the *stand.* Platforms for the pointer and trainer are bolted rigidly to the base of the carriage. A bracket for supporting the battery box is also secured to the carriage base. The arms of the carriage are now made with extending shoulders

to which are bolted armored shields for the protection of the gun pointers.

The stand projects into the hollow base of the carriage, where it is guided by upper and lower bushings bearing against the bearings within the carriage base. The weight of the carriage is borne by conical *rollers,* which turn on hardened steel *roller paths,* housed in the carriage base and stand. A flange projecting upward from the base of the stand supports the training circle and the indicator arc. Water-tight doors on opposite sides of the carriage base make the bearings readily accessible for inspection and give access to the *holding-down clips.*

The *sight* is supported on a *yoke* fastened to the lugs on the slide. The elevation and azimuth handwheels are conveniently located near the sight-setter's position on the left side of the mount behind the pointer.

The pointer's and trainer's telescopes are yoked together so that the same movements for elevation and azimuth can be made to both telescopes by one sight setter, and thus avoid the possibility of having the pointer's and trainer's telescopes disagree in adjustment. By the arrangement shown, the pointer and trainer are in effect observing the target through one telescope.

A voice tube, terminating in a megaphone near the sight setter, provides for communication between the mount and the fire-control station. Shoulder braces bolted to the hand-wheel bracket are provided for the pointer and trainer.

Action During Recoil.

371. Recoil is regulated by the by-passing of the recoil liquid through the grooves in the cylinder liners and by the simultaneous compression of the springs as the piston rods are withdrawn. At battery, practically all of the recoil liquid is in rear of the pistons since the pistons are designed to fit tightly against the forward cylinder heads. When the gun recoils, the energy is dissipated through the heat generated by the friction of the recoil liquid as it is forced by the piston head through the grooves in the cylinder liners. Pressure within each recoil cylinder during recoil is made approximately uniform by the design of the *throttling grooves* which vary with the stroke of the piston. Pressure between the two cylinders is balanced through an *equalizer pipe* connecting the

cylinders. Recoil is retarded partially by the recoil springs which are compressed during recoil; but the chief function of these springs is to provide energy to return the gun to battery. Counter-recoil momentum is dispersed as the counter-recoil plungers enter the counter-recoil chambers in the forward cylinder heads and force the recoil liquid through orifices provided.

The Frictionless Bearings.

372. The upper surfaces of the carriage cheeks are machined to provide slots into which fit *cap squares* secured with cap-square

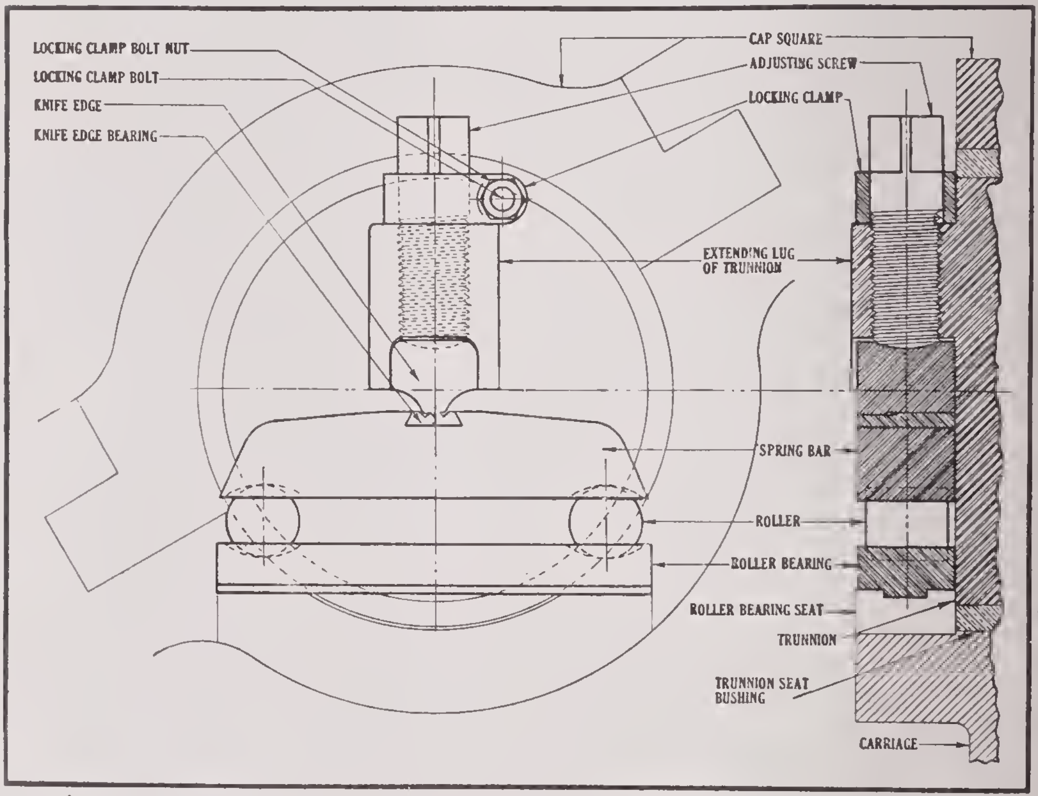


FIG. 62.—DETAILS OF FRICTIONLESS TRUNNION BEARING.

bolts (see Fig. 62). Lost motion resulting from wearing of the trunnion bushings or seats is eliminated by cap-square shoes fitting into slots in the cap squares. These wedge-shape shoes are forced into the slots by means of cap-square adjusting nuts turning on cap-square studs and bearing against shoulders on the outer ends of the cap-square shoes. The inner ends of the cap-square studs are screwed into the cap squares.

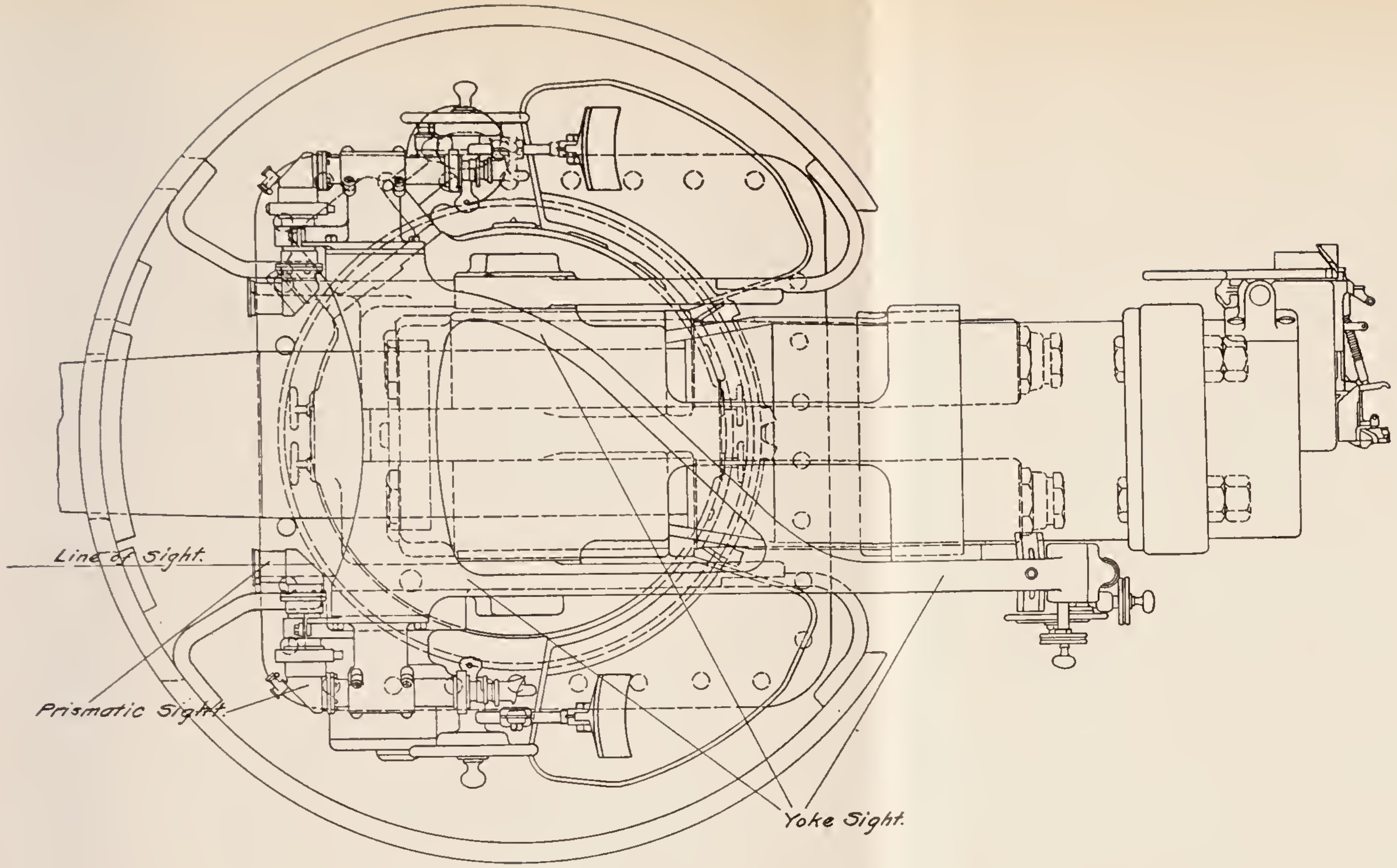


Fig. 1.

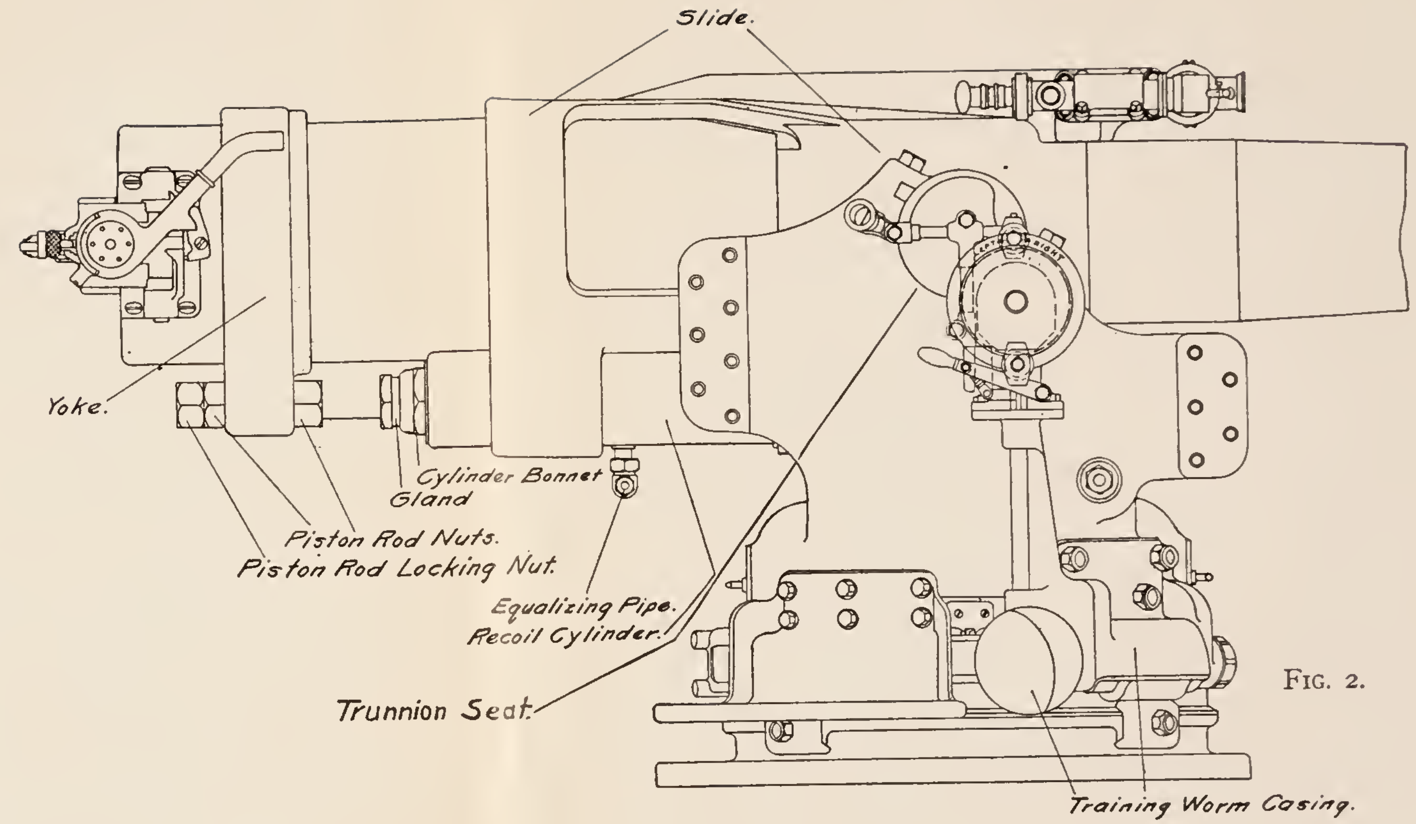


Fig. 2.

ONE TURN OF ELEVATING HANDWHEEL (HIGH SPEED) = 1°-12'-21" ELEVATION.
ONE TURN OF ELEVATING HANDWHEEL (LOW SPEED) = 50'-0" ELEVATION.
ONE TURN OF TRAINING HANDWHEEL (HIGH SPEED) = 1°-10'-44" TRAIN.
ONE TURN OF TRAINING HANDWHEEL (LOW SPEED) = 48'-53" TRAIN.

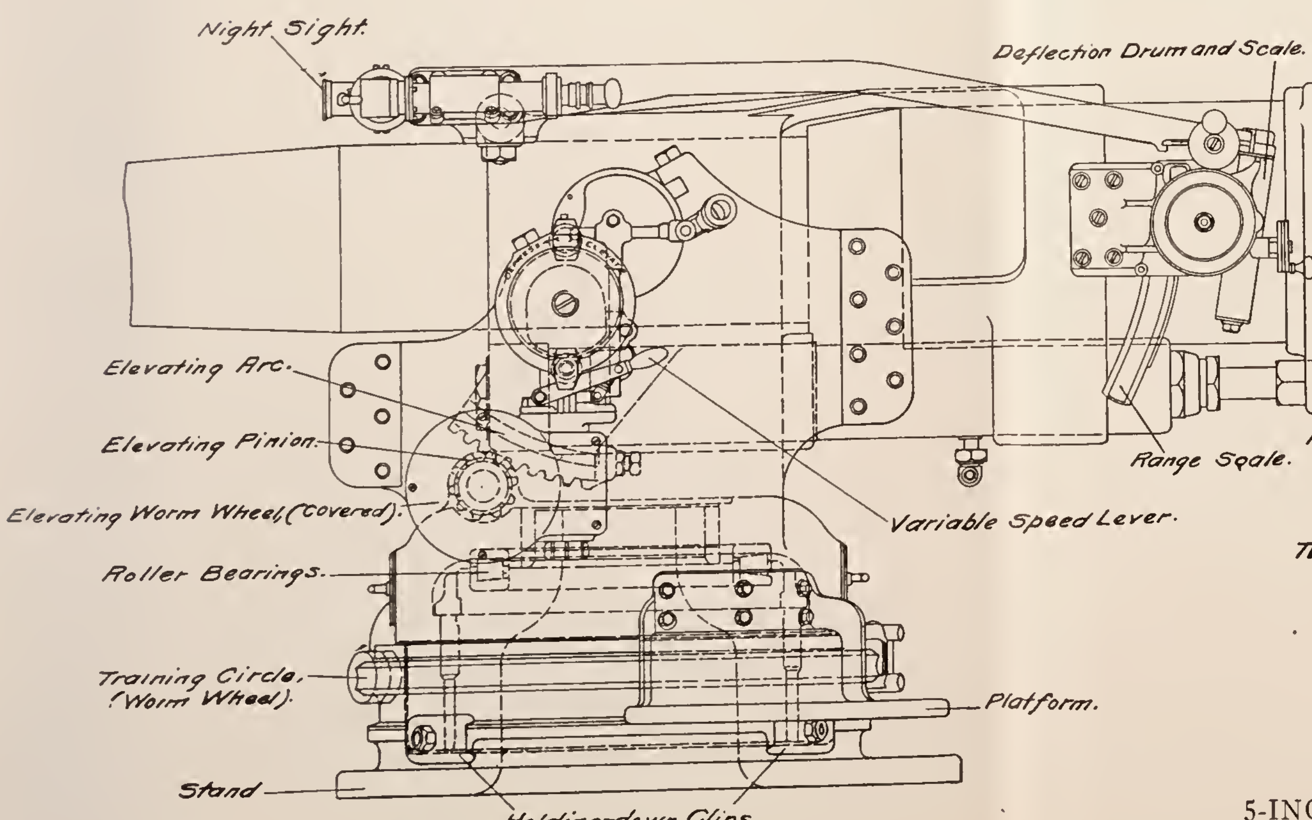


Fig. 3.

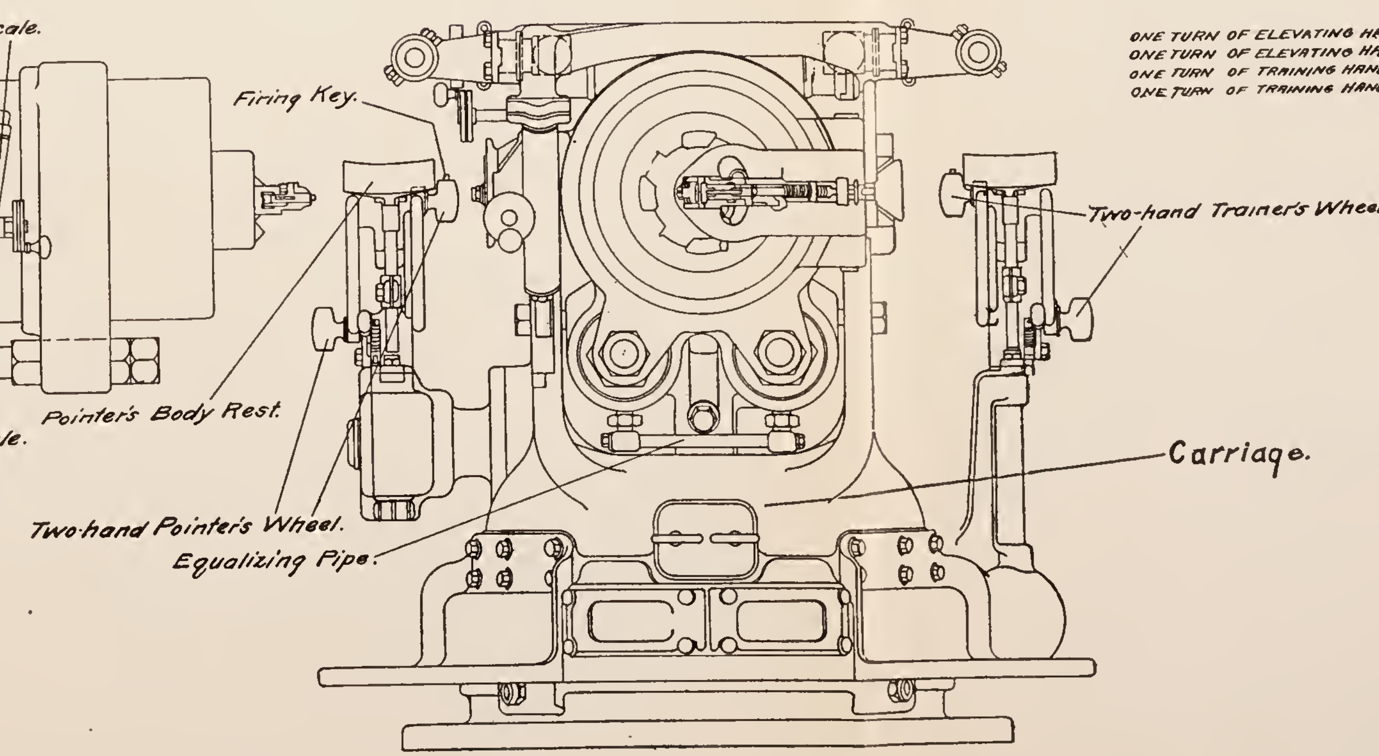
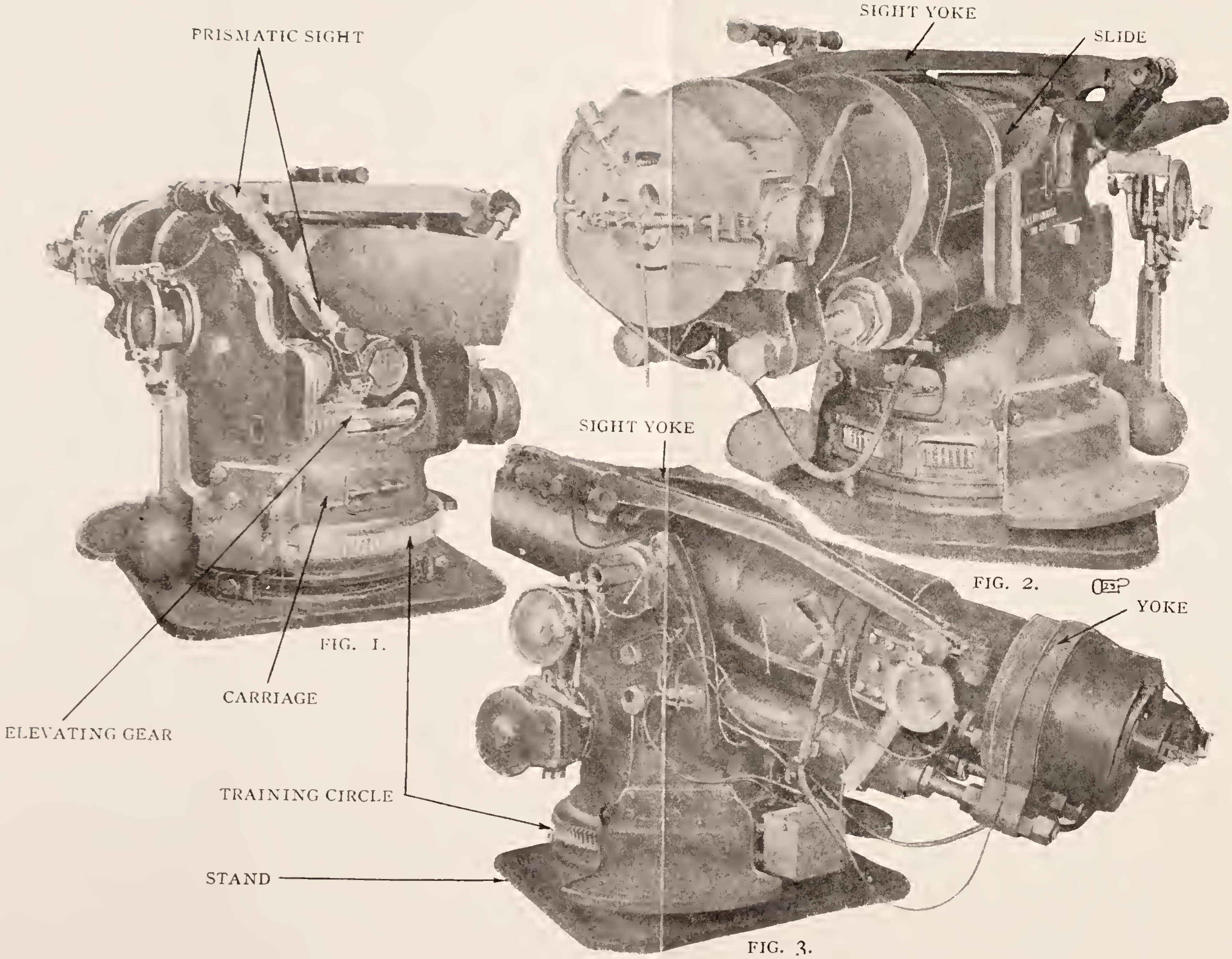


Fig. 4.

5-INCH MOUNT, MARK XIII, MOD. II.



VIEWS OF 5-INCH MARK XIII AND MODIFIED MOUNTS.

The *knife edges,* upon which the oscillating parts rock when the gun is elevated or depressed, are housed within pockets cut in extending lugs on the outer ends of the trunnion bosses. Each knife edge slides in the lower end of the recess of the trunnion boss and is adjusted and secured in position by an *adjusting screw* which threads through the extending lug and is maintained in the desired position by a locking clamp secured by a locking-clamp bolt. The dead weight of oscillating parts is transferred from the knife edge to a knife-edge bearing held by a drive fit in a slot in the upper surface of the spring bar. The *spring bar* is supported on two alloy-steel rollers. Curved recesses at each end of the spring bar serve as upper roller paths; similar recesses in the roller bearing function as lower roller paths. The roller bearing rests upon a projecting shoulder cast on the carriage cheek below the trunnion seat. When the gun is at rest, the weight of the oscillating parts is carried by these frictionless bearings which transfer the weight directly to the carriage cheeks; but when the pressure on these bearings is increased by firing, the spring bars deflect and allow the trunnions to bear against the trunnion seats, removing strain from the frictionless bearings and providing ample support for the gun and slide. The frictionless bearings are protected by trunnion bearing covers bolted to the carriage cheeks.

Adjustment of Frictionless Bearings.

373. If the gun and slide are not properly and accurately balanced on the trunnions the pointing mechanism will operate sluggishly. The cause for this generally will be found in the adjustment of the frictionless bearings rather than in balance of the gun within the slide. If the adjusting nuts are not adjusted so as to transfer the weight of the gun and slide to the spring bars, or if they are so adjusted that the trunnions are forced against the upper surfaces of their bearings, then the frictionless bearings will not function properly and elevation and depression will be difficult. These discrepancies may occur in either one or both bearings. Accurate adjustment of these bearings is easily accomplished by turning the adjusting nuts until thin test strips of paper may be inserted between the trunnions and their bearing surfaces, after which the adjusting nuts may be locked securely with the locking clamps provided.

General Discussion of Turret Mounts.

374. The turret installation on each class of ship varies, being a gradual development from type to type. For modern battleships the U. S. Navy has adopted the three-gun turret, four turrets per ship, combination as being the most efficient arrangement of main battery. In general, the developments in turret design have progressed from the use of a single gun in a turret, to a maximum of four guns in a turret. It may be accepted that this development is based upon sound principles and follows a corresponding increase in the size of the navies of the principal powers.

375. The primary objects to be accomplished in the design of a turret are accuracy and rapidity of gun fire, and efficiency and reliability of all mechanical features of the turret, combined with the maximum possible protection against damage by the enemy's gun fire. The details of gun and mount should be worked out to eliminate excessive dispersion, and to avoid any increase in dispersion, caused by any progressive permanent deflection in metal which is strained by the forces resulting from the discharge of the guns. The various machines installed for use in the service of the guns should be designed with a liberal factor of safety to insure continuous operation over an extended period of time, and should be simple in design to facilitate upkeep, and to avoid the necessity of too much mechanical skill and experience on the part of the personnel. Protection is similar to insurance against accident and should be the maximum which can be obtained without undue sacrifice of accuracy of gun fire and mechanical reliability.

376. The most important subjects that require consideration in connection with turret designs are:

(a) Accuracy of fire.
(b) Rate of fire.
(c) Simplicity and reliability of machinery.
(d) Strength and reliability of turret structure.
(e) Size of barbettes and dead weight of turrets.
(f) Safety features.

377. From the constructor's point of view, it has been practically demonstrated that the weight of installation per gun is the least for a three-gun turret, and increases in both directions from this number, due to the fact that the space occupied by that portion of the three guns contained inside the turret pan is bounded

very nearly by a square, which is the largest rectangle which can be inscribed in a circle of a given size. It is also true that the least weight is required for designs where all guns are carried in one slide, but flexibility is thereby lost.

378. The earlier turret designs in the U. S. Navy were two-gun turrets with what is known as a *single-stage hoist*. That is, the powder and shell were taken from the magazines and shell rooms and placed in a car for each gun, which was hoisted to the breech of the gun, traveling up and down in an open well. The guns were loaded, using rammers fixed in the rear of the turret, so that the guns had to be brought to the horizontal position to be loaded.

379. When modern target practice was introduced in the navy, about 1903, there occurred several very serious turret accidents, due to this open type of construction; and all turrets were modified by fitting them with automatic shutters, to seal the handling room from the turret chamber, except at the instant the car was passing the shutter. This was not entirely satisfactory, and new designs were made on the *two-stage-hoist* principle; that is, the powder and shell were brought up from the handling room in one set of cars, and transferred to another set which carried them to the guns. This permitted the introduction of a more positive flame seal between the turret chamber and the magazines. Variable loading positions were also provided by putting the rammer on an arm from the gun slide, thus permitting the gun to be loaded at any angle of elevation, as is still the practice in the British Navy.

380. A further change was soon made as the demands for rapidity and reliability of fire grew, and the turrets were nearly all converted to " hand loading." In this system the cars and rammers were done away with. The shell was hoisted vertically in a tube hoist, the powder passed up from the handling rooms by men standing on fixed platforms, and a wooden hand rammer was used.

381. With an increase in caliber over that of 12 inches, the weights involved became too great and a return to power loading became necessary. This also led to a reduction in the number of men required for the turret's crew.

382. The designs gradually developed to that now in use; by the introduction of the reciprocating shell-hoist tube, the separate powder car, and a chain rammer secured to the turret; thus again

necessitating a fixed loading position; the complications involved by retaining the variable loading feature not being considered justified. The importance of shell seating also led to the power rammers being re-installed in all 12-inch turrets of dreadnoughts.

In the latest 16-inch turret designs the reciprocating powder hoist car has been replaced by a conveyor hoist similar to that used for broadside guns, and in all the later turrets the use of straight electric control has been replaced by control through universal speed gears, as will be seen in the detailed description following:

14-Inch Three-Gun Turrets.

383. The description which follows applies generally to turrets of vessels of the *New Mexico* and *California* classes.

The principal parts of a turret mount are: (1) The gun, breech mechanism and yoke, (2) slide, including recoil and counter-recoil mechanism, (3) deck lugs, (4) elevating and training gear, (5) shell and powder hoists, (6) rammer and spanning tray, (7) sights. (See Plates III and IV.)

The *turret booth* is an enclosed space in a turret occupied habitually by the officer in command of the turret when in operation. (See Plate III.)

The *turret chamber* is that part of the turret surrounding the gun positions. It includes the *gun chambers* and the *gun pits.* It does not include the *center girder* spaces nor the *wing girder* spaces, when these are separated from it by the nature of the construction.

The *magazines* are enclosed spaces in which powder is stowed.

The *shell rooms* are enclosed spaces in which the projectiles are stowed. *Shell stowage* is the term used to designate open spaces where shells are stowed.

The *handling rooms* are spaces not mentioned above which are habitually utilized in the ammunition supply train for transferring powder or shell from their stowage to the supply hoists, from one hoist to another, or from one means of supply to another means of supply. These may be further distinguished as *powder-handling room* and *shell-handling rooms.*

Each turret has a *turret booth* separated from the turret chamber by flame-proof bulkheads, and so designed as to give the turret officer a direct view of the guns through suitable dead lights. Access to the turret chamber is obtained through suitable doors.

Each turret booth has a quick-acting lever or other device for operating mechanically the sprinkling system in the turret chamber. The turret booth is also fitted with a lever or other device for operating mechanically an emergency alarm.

384. The general requirements regarding turret construction require that nothing shall be attached to the turret armor except fittings required by the structure, or which by their nature and use cannot otherwise be placed for the efficient operation of the turret. Means are provided to prevent bolts, nuts, rivet heads, etc., flying in the turret as the result of shell impact. In all turrets, except three-gun single-slide turrets, flame-proof bulkheads are fitted to separate the several guns from one another.

385. A *gun spray* is installed near the breech of each gun and fitted with a quick-acting valve controlled from the turret booth and gun chamber. This spray is fitted on the end of a flexible hose capable of being used in the gun breech or any other part of the turret gun chamber.

386. Each gun in the turret is fitted with a *gas-expelling device,* and blowers are installed in the turret for ventilating purposes. A sprinkling system is also installed to drench powder in the upper handling room where exposed in case of fire. Voice tubes, bells, buzzers, telephone and fire-control instruments are also installed as called for by the latest instructions. The usual fittings installed on the forward bulkhead of the turret officer's booth are shown in Plate V.

387. The intakes of the turret ventilating system are so located as to minimize the possibility of drawing into the system gases from fires in action. Care is taken, in so far as practicable, to keep water and spray from entering the turrets through the gun ports, and sighting slits, while the turrets are being operated.

388. All machinery of a modern turret is electrically operated and speed is controlled through universal speed gears.

389. The turret structure, to which the armor and all revolving parts of the turret are secured, is built up of rolled-steel plates and angle irons, and revolves on rollers supported by a roller path which is secured to the structural steel foundation built into the hull of the ship, and included inside the barbette armor. (See Plates III and IV.) The rollers which are frustrums of cones, are spaced by a separator ring floating on the roller axles. The weight and vertical forces resulting from firing, are supported by

the conical surface of the roller, and the horizontal thrust due to firing, is transmitted from the revolving structure to the turret foundation through the roller flanges. The turret is also provided with *holding-down clips* (see Plate III) to prevent it from being thrown from its foundation by force from any outside source. The circular barbette armor extends from a point just below the armor secured to the revolving portion of the turret, down through the space between decks to the protective decks of the ship, so that the turret roof, front, and side plates, together with the barbette and protective-deck armor afford protection to the guns and machinery within.

390. The turret-revolving structure is rotated by *the training-gear* machinery driven by an electric motor and *universal speed gear*. (See paragraph 402.) The driving end of the speed gear connects directly to the worm shaft which drives the worm wheel attached to the training pinion shaft. The *training pinion* (see Plate IV) which is secured directly to the training-pinion shaft, meshes with the training rack secured to the turret roller path foundation.

391. In the latest ships, two sets of worm wheels and pinions are used. The gears are driven by one main electric motor through a special arrangement of universal speed gears. The torque is transmitted from the motor to the training pinion direct without the use of friction discs, such as were used in the older turrets. In this case, the gear is designed with sufficient strength to withstand the forces resulting from the firing of the guns, and the inertia of the turret due to starting and stopping.

392. **Auxiliary training gear** is provided for use in case the main electric motor or speed gear becomes disabled. This gear consists of a low-powered electric motor receiving current from storage batteries stowed in the revolving structure. The speed of train, as in the case of the main gear, is controlled through a small universal speed gear. Hand training is also provided for emergencies when power is not on the turret. This gear is not efficient, and is inadequate for training the turret, at any satisfactory speed, being merely provided as a last resort.

393. **The deck lugs,** which contain the trunnion seats and cap squares, are heavy steel castings bolted to the gun girders. The gun girders form the supports for the deck lugs and elevating

gear; and through them the firing forces, at the trunnions, are transmitted to the roller path. (See Plate IV.)

394. The gun slide, to which the trunnions are secured, supports the gun and the recoil mechanism. The slide is of cast steel and is lined with bronze. The trunnions about which the guns are moved in elevation, are located approximately at the center of gravity of the oscillating weights which they support. In the latest turrets, these trunnions are of special form, designed to reduce the size of the port opening through the turret front plate.

395. The recoil mechanism, consisting of the recoil cylinder and throttling rods, is attached to the slide. The piston rod is attached to the gun yoke and recoils with the gun. During recoil, the liquid in the cylinder is forced through the orifices formed between the throttling rods and the apertures in the piston. These orifices are so proportioned that the resistance to recoil is practically constant for the whole distance, and of sufficient magnitude to check the recoil in the distance allowed. In the latest turrets one recoil cylinder is used with two to three throttling rods, depending upon circumstances. The method of computing the proper dimensions of throttling rods is discussed in the chapter on Recoil.

The energy absorbed by the hydraulic brake results in a considerable heating of the recoil cylinder liquid. When the gun is fired rapidly, the heating effect is accumulative and results in a considerable rise of temperature and expansion of the recoil cylinder liquid. This expansion, unless compensated for in some manner, interferes with the return of the gun to its battery position. The expansion of the liquid is therefore compensated for by means of an *expansion chamber* which has been provided for all turrets. By means of this chamber, space is provided for the expansion of the liquid and the capacity of the chamber is sufficient to meet all service requirements. This chamber is connected to the forward end of the recoil cylinder. It functions automatically, and requires no attention except the exercise of ordinary precaution, during the process of filling the recoil cylinders, to see that the expansion chamber remains empty.

The recoil mechanism performs its primary function during recoil, but it has a limited effect also on counter recoil.

396. **The counter-recoil mechanism** which is also attached to the slide, is provided for the primary purpose of returning the gun to the battery position at all angles of elevation, and although this is its primary function, it has a limited effect on recoil.

Until recently, the force for returning the guns to battery was derived from the compression of helical springs, but on account of the large increase of the recoil weights and the angles to which guns are now elevated, springs are impracticable on account of the limited amount of work that can be stored up in a spring system. The return of the gun to battery in the latest mounts is accomplished by compressed air.

This system (pneumatic) is not subject to the same limitations as the spring system, since the pressures and dimensions of the counter-recoil cylinders can be increased to the proper amount. The initial air pressure varies from 800 pounds to 2000 pounds per square inch. This pressure is held indefinitely without leakage by the special packing used. Upon returning to battery, the recoiling weights are brought to rest by means of a counter-recoil plunger and dash pot which operates in the same manner as described for the recoil cylinder proper. With the parts properly designed, the guns return to battery without shock.

397. **The elevating gear** (see Plates III and IV).—In the latest turrets the guns are arranged to elevate independently. Under normal conditions, however, all three elevating gears are locked together by clutches so that all guns elevate together. The elevating gear provided for all guns is similar. Sufficient power is provided in each set so that all three guns may be operated by any single set of electric and hydraulic motors. In case of a casualty which would increase the resistance imposed upon the elevating gear, the guns may be elevated with all three electric motors and speed gears operating simultaneously. The elevating gear for each gun consists of an electric motor driving a universal speed gear. The "B-end" of the speed gear connects to the elevating nut which drives the elevating screw attached to the slide. The elevating nut is supported by the oscillating bearing which in turn is supported by the transom casting attached to the turret structure. Rotation of the elevating nut imparts an up-or-down motion to the elevating screw depending on the direction of rotation of the nut.

The rate and amount of elevation of the guns is controlled through a two-hand drive connecting to the control shaft of "A-end" of the hydraulic-speed gear. This two-hand drive is located in a convenient position with reference to the sight telescope and gun-pointer's seat, so that the gun pointer may keep his eye on the telescope for all positions of the gun in elevation.

The "follow-up" type of control is used; one turn of the hand wheel produces a definite angle of elevation of the gun; and the direction of rotation of the gun about the trunnion axis corresponds in direction, to the direction of rotation of the hand wheel. A definite ratio also exists between the rate of rotation of the hand wheel and the rate of elevation of the guns, and when the hand wheels come to rest, the gun is brought to rest. With the type of control described the guns can be operated with the same facility as a hand operated mount.

398. The **training-gear control** also has a similar "follow-up" arrangement.

399. **Powder supply** (see Plates III, IV and VI).—The powder is stowed in the powder magazines in air-tight powder tanks. In supplying powder to the guns the powder is taken from the tanks and passed through flame-proof scuttles in the magazine doors to the powder-handling room. From this point the powder is carried by hand to trays located at the lower end of the powder conveyor. The trays rotate with the revolving portion of the turret and maintain a fixed relation to the hoist. From the trays in the lower handling room the powder bags are fed into the receiving end of an endless-chain conveyor hoist. Two hoists of this type are used. These hoists deliver the powder bags to the trays located in the upper powder-handling room beneath the pan separating the turret gun chamber from this room. One charge for each gun is assembled in this room for transmittal to the guns as required.

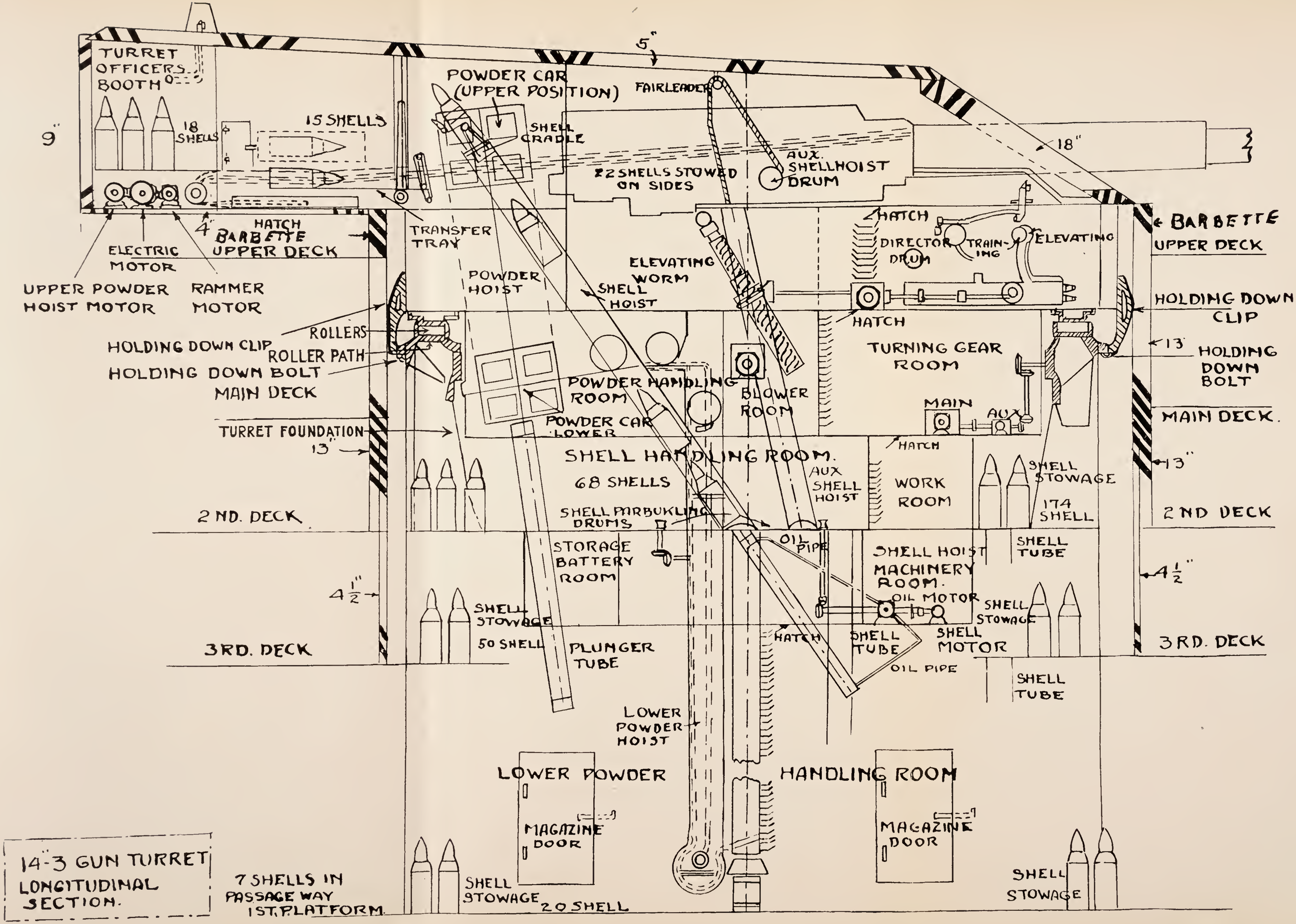
From the upper powder-handling room, the powder bags are loaded into the upper powder cars which convey the powder from the upper powder room to the breech of the guns. One powder car is provided for each gun, and each car is arranged to carry a complete charge per trip. The charge is hoisted while the shell is being rammed into the gun. The powder car is flame-proof so that the charge is completely protected from flare-backs until the bags are dumped out into spanning trays prior to being rammed

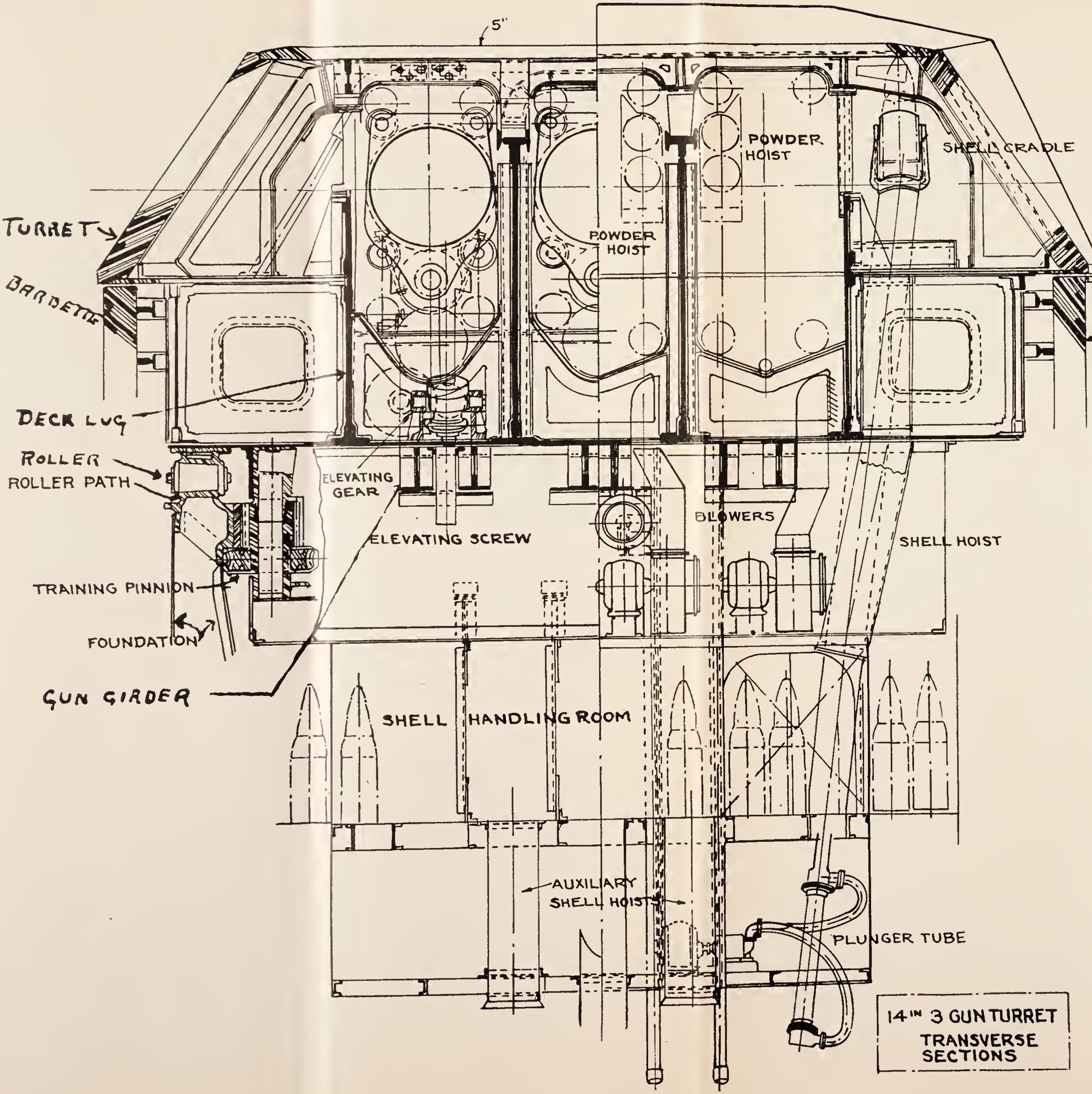
into the gun. The upper powder hoist is of a reciprocating type, hydraulically operated. An "A-end" of speed gear serves as a pump and delivers liquid under pressure. The motion of the car is controlled by the movement of the control screw of the speed gear. Flame-proof doors form a seal between the upper powder-handling room and the gun chamber of the turret, so that there can be no direct communication at any time between the gun chamber and the upper powder-handling room.

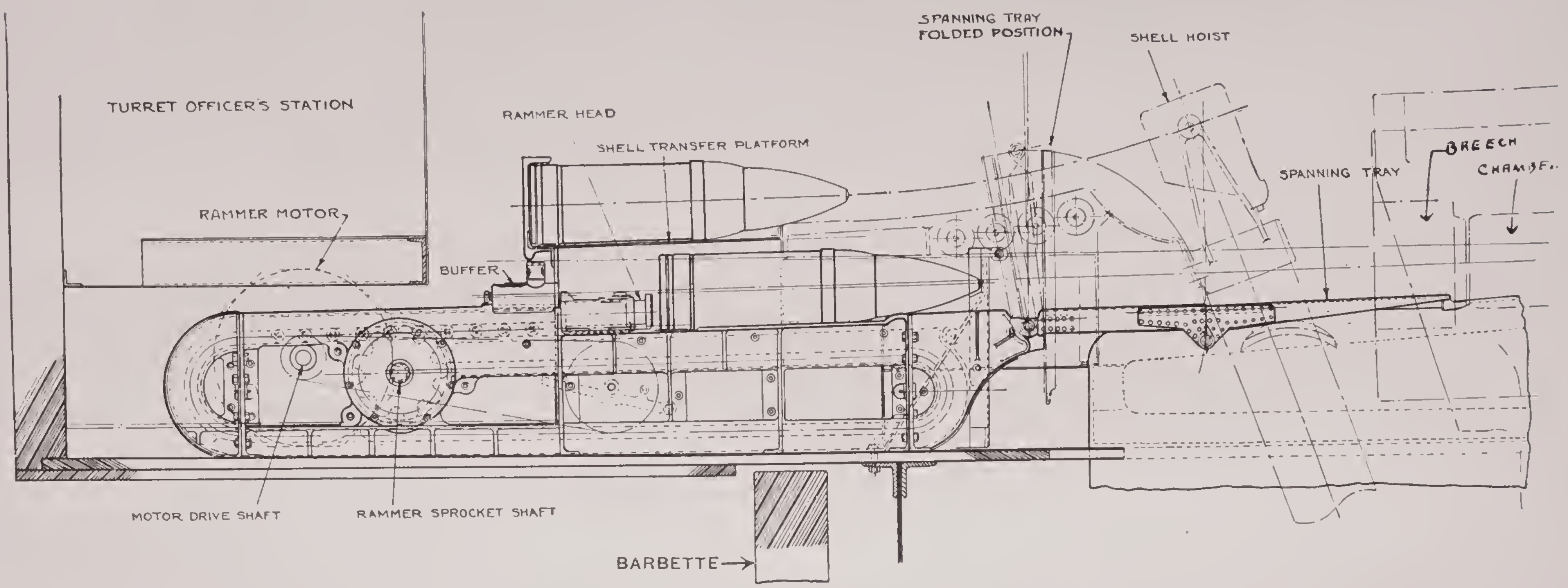
In case power is not available for hoisting powder, the powder bags may be hoisted from the lower handling room to the upper powder-handling room by means of a whip hoist provided. Upon arrival in the upper powder-handling room the powder bags are passed through hatches in the upper powder hoist trunk to the breech of the gun by hand. Platforms are provided for the use of the powder-passing crew.

400. **Shell hoists** (see Plates III, IV and VI).—The shell hoist, which is a standard navy type, extends from the shell-handling room, located directly below the upper powder-handling room, to the gun chamber, at a point opposite the breech of each out-board gun. Two hoists are used. Shells are stowed on platforms in the turret foundation space and in the shell-handling room. The shells are stowed in both positions on their bases in such a way that one shell can be removed from its fastenings without disturbing the adjacent shells. The shell is parbuckled from its stowed position to the hoist by means of a manila rope running over a winch driven by the shell-hoist motor.

From its position in the lower end of the shell hoist the shell is raised by a series of short strokes to the gun chamber above. At the termination of each stroke a shell arrives at the gun and another shell is loaded into the hoist. The hoist is hydraulically operated by means of an "A-end." of a hydraulic speed gear. The speed gear which acts as a pump delivers liquid under pressure to a ram which actuates a rack bar and pawls which raise the column of shells in the hoist. During the return stroke of the ram the shells are supported by a series of pawls fixed to the shell tube. The motion of the hoist is controlled through the control screw of the hydraulic speed gear. The shells are dumped out of the upper end of the hoist by means of a cradle from where they are rolled to the guns.


TURRET OFFICERS BOOTH
18 SHELLS
15 SHELLS
POWDER CAR (UPPER POSITION)
SHELL CRADLE
5"
FAIRLEADER
22 SHELLS STOWED ON SIDES
AUX. SHELLHOIST DRUM
18"
9"
4"
HATCH
BARBETTE UPPER DECK
ELECTRIC MOTOR
UPPER POWDER HOIST MOTOR
RAMMER MOTOR
TRANSFER TRAY
POWDER HOIST
SHELL HOIST
ELEVATING WORM
HATCH
DIRECTOR DRUM
TRAIN-ING
ELEVATING
BARBETTE UPPER DECK
HOLDING DOWN CLIP
ROLLERS
HOLDING DOWN CLIP
ROLLER PATH
HOLDING DOWN BOLT
MAIN DECK
HATCH
TURNING GEAR ROOM
13"
HOLDING DOWN BOLT
POWDER HANDLING ROOM
BLOWER ROOM
MAIN
AUX
MAIN DECK.
TURRET FOUNDATION
13"
POWDER CAR LOWER
HATCH
SHELL HANDLING ROOM.
68 SHELLS
AUX SHELL HOIST
WORK ROOM
SHELL STOWAGE
174 SHELL
13"
2 ND. DECK
SHELL PARBUKLING DRUMS
OIL PIPE
SHELL HOIST MACHINERY ROOM.
SHELL TUBE
2 ND DECK
STORAGE BATTERY ROOM
4 1/2"
4 1/2"
OIL MOTOR
SHELL STOWAGE
SHELL STOWAGE
50 SHELL
PLUNGER TUBE
HATCH
SHELL TUBE
SHELL MOTOR
OIL PIPE
3RD. DECK
3RD. DECK
SHELL TUBE
LOWER POWDER HOIST
LOWER POWDER
HANDLING ROOM
MAGAZINE DOOR
MAGAZINE DOOR
14-3 GUN TURRET LONGITUDINAL SECTION.
7 SHELLS IN PASSAGE WAY 1ST. PLATFORM
SHELL STOWAGE
20 SHELL
SHELL STOWAGE


5"
POWDER HOIST
SHELL CRADLE
TURRET
BARBETTE
POWDER HOIST
13"
DECK LUG
ROLLER
ROLLER PATH
ELEVATING GEAR
BLOWERS
ELEVATING SCREW
SHELL HOIST
TRAINING PINNION
FOUNDATION
GUN GIRDER
SHELL HANDLING ROOM
AUXILIARY SHELL HOISTS
PLUNGER TUBE
14 IN 3 GUN TURRET TRANSVERSE SECTIONS


SPANNING TRAY
FOLDED POSITION
SHELL HOIST
TURRET OFFICER'S STATION
RAMMER HEAD
SHELL TRANSFER PLATFORM
BREECH
CHAMBER
SPANNING TRAY
RAMMER MOTOR
BUFFER
MOTOR DRIVE SHAFT
RAMMER SPROCKET SHAFT
BARBETTE

When power is not available in the turret for running the shell hoist, shells may be hoisted to the turret chamber by means of a chain purchase using an auxiliary tube.

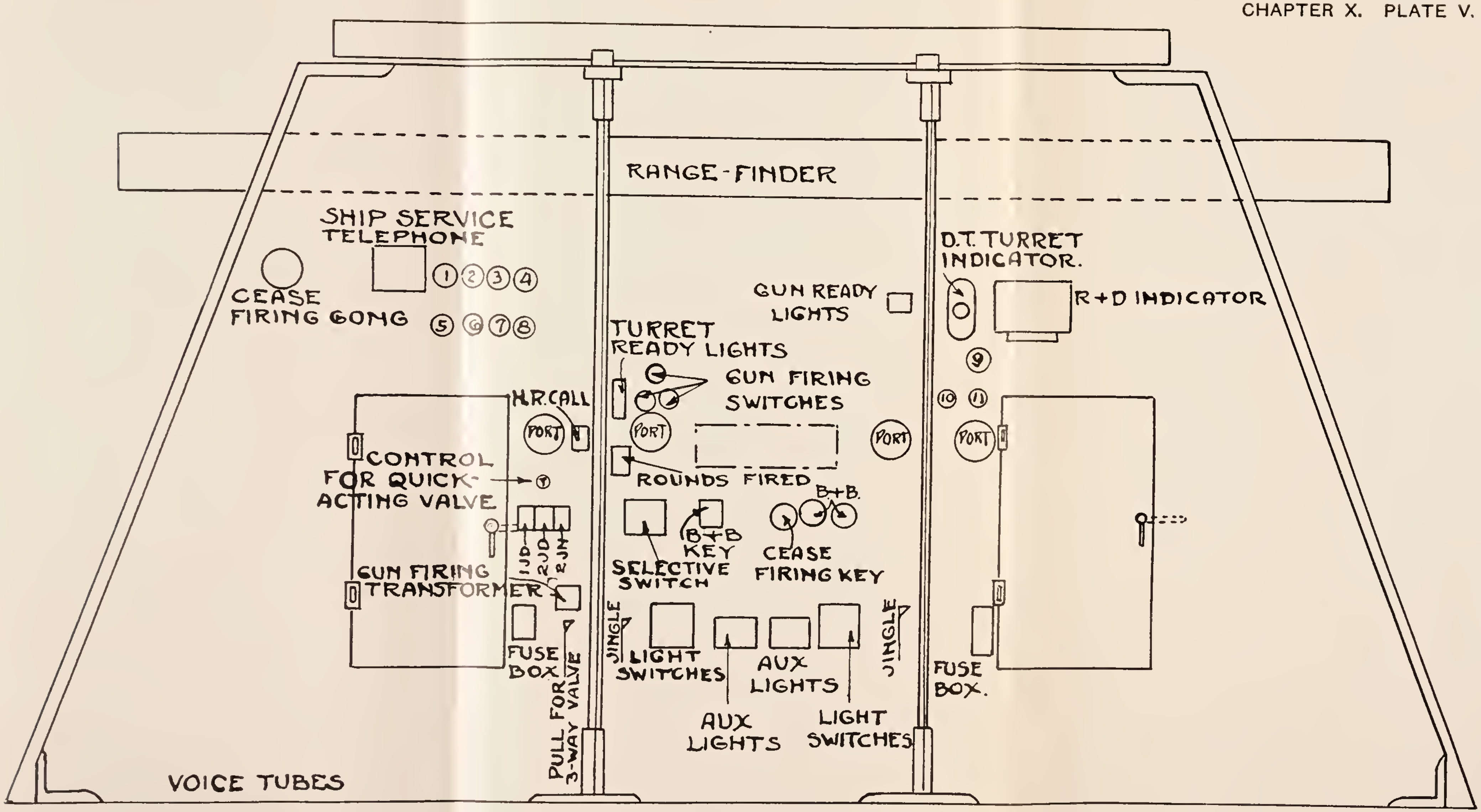
401. **Rammer and spanning tray** (see Plate VI).—The shell and powder charge are rammed into position in the gun by means of a chain rammer. The guns are loaded at a fixed loading angle. After opening the breech, *the spanning tray* is carried forward from its folded position, at the forward end of the rammer, so as to extend into the chamber of the gun. The shell is then rammed from its position in the *rammer tray* to its position in the gun by means of a chain. After loading the gun the tray is folded back clear of the recoil position of the gun. The *rammer head* is attached to the end of the chain that comes in contact with the shell, and is provided with hydraulic buffers to relieve the rammer mechanism of shock. The chain is contained in a rammer casing and is driven by a sprocket which in turn is driven by a hydraulic speed gear. Motion is controlled through the control shaft of the speed gear, so that the speed may be varied, as required.

The Waterbury Hydraulic Speed Gear.

402. The Waterbury hydraulic speed gear (Plates VII and VIII) is a machine for transmitting rotary power at variable speeds and in either direction without steps or abrupt gradations, while the source of power rotates continuously in one direction without any necessary change of speed. This source may be an engine of any kind, an electric motor, a shaft or any rotating mechanism from which it is desired to transmit power. The medium of transmission is oil. This being practically incompressible, the driving is very positive, except to the extent of the very slight leakage necessary for lubrication.

403. **" A-End " and " B-End."**—Functionally the machine consists of two separate mechanisms designated, respectively, the A-end and the B-end.

The A-end is an oil pump operated by the driving power, whatever that may be. Its function is to deliver oil to the B-end at any required pressure and receive it back again, thus keeping up an oil circulation. The A-end contains a controlling device by which the quantity of oil delivered to the B-end is regulated exactly to meet the speed requirements of the B-end. The shaft of the



1 WORK SHOP
2 OVERHANG TURRET
3 BREECH OF EACH GUN
4 SHELL HANDLING ROOM
5 POWDER HANDLING ROOM
6 LOWER HANDLING ROOM
7 TRAINERS + POINTERS
8 SHELL HANDLING ROOM

9 _ TO OTHER TURRETS OF SAME GROUP
10 _ TO PLOTTING ROOM FROM RANGE FINDER
11 _ TO SUB

NOTE:-ALL VOICE TUBES TURNED THRU ANGLE OF 90° INBOARD

14 IN 3 GUN TURRET
TURRET OFFICERS' STATION

A-end is supposed to rotate in one direction only, at a constant speed.

The B-end is a hydraulic engine. Its rotating parts are almost exactly like those of the A-end. In its capacity as an engine its shaft rotates at any speed and in either direction in exact obedience to the quantity and direction of delivery of the oil it receives from the A-end.

404. Arrangement of the Ends.—When conditions permit, the two ends are united into one machine, a middle partition, called a *valveplate* or *midplate,* separating the two parts. If the two shafts are to stand in a straight line, the valveplate is a flat disc with parallel faces. If, however, the shafts are to stand in any other position than a straight line, the shape of the valveplate may be varied to meet the requirements.

The conditions of installation may be such as to require the locating of the A- and B-ends some distance apart. Each end will then have its own valveplate, which may be appropriately termed an "*endplate.*" The two endplates will have their two main oil passages connected by two pipes. Since the chief function of the valveplate or endplates is to furnish passages for the circulation of oil between the two ends of the gear, it is evident that the connecting pipes may be so bent as to make the possible variety of arrangements unlimited.

405. Description.—To simplify the description let us consider only the unitized or C-type of machine wherein the shafts are in line with each other.

The fixed or non-rotating parts, which *do not* rotate with the shafts in the transmission of power, are the cases, the valveplate, the tilting box, the angle box and the control shaft.

All the working parts of the machine are enclosed within cylindrical shells, called *cases,* one for each end of the machine. The open, or large, ends of the cases are securely bolted against the opposite faces of the valveplate by long bolts passing through the cases and the valveplate. The other ends of the cases are closed into form hubs through which the shafts extend. Legs cast on the cases provide means for securing the machine to its support.

Thus combined the cases form an oil reservoir within which the active parts rotate. The greater portion of the oil is not under pressure, but is in communication with the air through the *oil*

expansion box on top of the case. The only active oil, which is directly used in transmitting the power, is enclosed within the *port passages* of the valveplate and within the cylinders ahead of the pistons.

406. Valveplate or midplate is a very important element of the machine. On each of its faces is carefully prepared a contact surface against which the face of a cylinder barrel slides in its rotation. Through these surfaces are two semi-annular passages, called *valveplate ports,* one in each half of the plate, extending from the A-face to the B-face, through which the oil circulates when transmitting power. Between the ports both at the top and the bottom are flat faces called *lands*, into which are cut short reduced extensions from the ports. As the cylinder barrel rotates, the cylinder ports pass in succession across these lands and the contents of each cylinder is for the moment imprisoned within the cylinder while being carried across from one port to the other At the center of the valveplate are bearings for the inner ends of the shafts. Several valves are also located in the valveplate, which will be described further on under the heading "*minor parts.*"

407. Tilting Box and Angle Box.—The purpose of the *tilting box* in the A-end is to carry a *thrust roller track* against which the *socket ring* may rotate in a plane at any desired angle to its shaft. In the earlier designs there were two tilting boxes, one in each end of the machine, but later the B-tilting box was displaced by a wedge-shaped casting, called the *angle box,* carrying its roller track at an angle of about 20 degrees from perpendicular, and screwed securely to the end of the inside of the B-case. This substitute for the tilting box is possible for the B-end, since the angle is not changed after once being set. But in the A-end the tilting box must be retained for the reason that the speed and direction of rotation of the B-end are controlled by changing the angle of the tilting box. The tilting box is suspended, and may be oscillated, on two trunnions, which are formed on the box itself and which bear in bronze bushings set in the sides of the case. An elongated hole is cut through the bottom of the box so as to give a free passage for the main shaft even when the box is tilted to its maximum angle. The box is retained in its bearings by two tilting box retaining trunnions which are screwed through from the outer sides of the case and enter bushed holes in the box.

Projecting from the bottom of the box are four fingers or prongs forming guides or slideways for the guide blocks connected with the control shaft.

408. Control shaft.—The purpose of the *control shaft* is to tilt the tilting box on its trunnions either way from the neutral or perpendicular position according to the direction and speed required of the B-shaft. It is a threaded shaft provided with a *thrust flange,* or collar, made integral with the shaft. This flange bears between two fibre thrust rings, the under one of which rests in the *control shaft hanger.* The upper one is adjusted against the flange by the control shaft bearing, which is screwed into the hanger and locked by the bearing nut. The hanger itself is screwed into the threaded mouth of the hanger housing, which forms a part of the case. The lower end of the control shaft bears very freely in a socket in the control shaft-guide plug, which is screwed into the bottom or lower end of the housing.

The threaded portion of the control shaft carries a trunnioned nut, whose trunnions carry four guide blocks, two on each trunnion. The outer two of these blocks slide in guideways planed in the sides of the housing. The inner blocks slide between the fingers of the bottom of the tilting box.

The turning of the control shaft causes the trunnioned nut to move up or down, carrying with it the fingers of the box. The angular positions of the tilting box are therefore determined by the rotation of the control shaft.

409. The rotating parts of the A- and B-ends are alike except the location of the sockets in the socket rings and of the cylinders and ports in the cylinder barrels. We may, therefore, confine our attention to one end only. These parts are so assembled upon the shaft as to form what may be called a shaft group, comprising the shaft, the cylinder barrel with the keys that connect it with the shaft, the socket ring with the universal joint that connects it with the shaft, and the pistons and connecting rods.

410. Shafts.—The A- and B-shafts are alike. Bushings in the hubs of the cases form the main bearings, while the inner ends of the shafts are provided with roller bearings in the valveplate. The ends of the two shafts are separated in the valveplate by a fiber disc called the *inter-shaft disc.* At the intersection of the plane of the socket ring the shaft is formed into a closed yoke around the universal-joint parts described under *universal joint.*

Where the shaft passes through the *barrel* it is flattened on two sides and perforated to receive the *barrel keys* and is threaded to receive the *barrel nut.*

The barrel nut performs no other function than to prevent the barrel from sliding off the shaft when the assembled group of shaft, barrel, and socket ring are being handled. When the gear is fully assembled and in operation the barrel does not touch the nut.

411. Cylinder barrel.—The cylinder barrel contains nine cylinders. It is loosely attached by two keys provided with pivots fitting loosely in a hole through the shaft. The loose fit of the barrel on the shaft together with the pivoted keys gives it a slight freedom of motion so that its face can rest squarely against the face of the valveplate. Moreover, it can slide freely endwise along the shaft. This endwise motion is aided by a *barrel spring* backing against a flange on the shaft. The purpose of the spring is to hold the barrel against the valveplate when not in operation. When the oil is under pressure, the barrel is held against the valveplate automatically by reason of the fact that the cylinder ports are smaller than the pistons, giving an excess internal pressure, forcing the barrel towards the valveplate.

The cylinder barrel and keys do not transmit any of the working torque.

412. Pistons.—There are nine pistons in each barrel, the pistons and cylinders being ground and lapped to a smooth working fit without any packing. Narrow shallow grooves are cut around the pistons, which serve to interrupt the leakage stream lines and to trap dirt.

413. Connecting rods.—Each piston is connected to the socket ring by a *connecting rod.* The rods have perfectly spherical ball ends of unequal diameters. The smaller end is secured into a socket formed in the piston, which it fits perfectly, by a bronze split piston-socket bushing which is secured in place by a finely threaded piston-socket cap.

The main purpose for having one ball end smaller than the other is to make it possible to string the ring-socket cap and the piston-socket cap over the smaller end; the smaller ball is held from being drawn back through the piston-socket cap by the split bushing.

The large ball end is secured in a socket in the socket ring by the ring-socket cap.

Through the end of the piston and through the whole length of the connecting rod is a small hole which feeds oil under pressure from the active oil system to lubricate the balls and sockets.

414. **Socket ring.**—The socket ring has cut into it nine sockets fitted with bronze ring sockets against which rest the large ball ends of the connecting rods. These sockets are unequally spaced to correct certain irregularities of the universal joint.

The back of the socket ring is provided with a chrome-venadium roller track which has two roller faces, one for the main conical thrust rolls and the other for the diagonal thrust, or cylindrical, rolls.

The body of the socket ring extends inward in four arms forming slots, or key-way shaped pockets, into which the bronze main shaft trunnion-bearing blocks are secured by the main shaft trunnion-bearing block screws.

415. **Universal joint** connects the shaft and socket ring. This joint consists of a shaft trunnioned block oscillating with the main *shaft pin* in the yokes of the main shaft. The trunnions of the trunnioned block operate in the bronze bearing blocks secured in the socket ring as mentioned above.

The entire working torque of the gear is transmitted through the socket ring, the universal joint trunnions, and the main shaft pin.

MINOR PARTS.

416. **Replenishing valves.**—There is necessarily a small amount of leakage of oil from the high pressure active portion into the inactive body of oil enclosed in the cases. Provision must be made to replace this leakage as fast as it occurs, otherwise there would be a vacuum in the cylinders and port passages. For this reason there are two check valves in the lower part of the valveplate called *replenishing valves.* One of these is connected with each port passage, and permits the oil to flow freely from the case space into the port passage, but prevents its flowing in the opposite direction.

The valve itself is a steel ball. The seat is a steel piece screwed in from the outside. The hole in the valveplate through which the seat was inserted is closed by a plug called the replenishing-valve cap.

417. Relief valves.—In the transmitting of power at very low speed in the B-end it is possible that the oil pressure may rise to thousands of pounds per square inch should the resistance to be overcome be correspondingly great. It is therefore necessary to provide safety valves to be set at any desired maximum pressure, say 1000 or 1200 pounds. Should the pressure exceed this amount the oil will escape from the high pressure port passage through a *relief valve* into the case space and flow back again through a replenishing valve into the low pressure port passage.

The relief valve group consists of a valve, a spring, a plug, and adjusting washers. The plug forms the backing for the spring, whose compression is adjusted by the use of more or fewer copper washers under the head of the plug.

418. Air valves.—At the highest points in the two port passages are needle valves. The purpose of these is to allow any air that may be imprisoned in the passages to escape into the case space, whence it can rise through the oil expansion box. It is only necessary to open these valves one or two turns during the filling process, after which they are to be closed tight, and perform no other function.

Thimble caps are screwed over the ends of these valve screws to prevent oil from leaking out or air from being sucked in.

419. Oil expansion box.—As the proper functioning of the machine requires that the medium of power transmission be practically incompressible, it is important that no air be allowed to mix with the oil. The case must therefore be entirely full of oil. To meet this requirement fully it is necessary to have the oil in the machine connected with an external supply that will always be in communication with the interior and yet not permit the entrance of air. The oil expansion box serves this purpose. In the illustrations the box is represented as connected directly with the top of the case. In practice, however, the box may be located in any convenient place near by and connected with the case by a pipe. The connections should always be such as to allow the easy escape of air from the case.

In the lid of the box will be noticed a baffle. Immediately above this are holes in communication with the outside air. The baffle prevents the splashing of the oil in the box from stopping the air holes, should there be a sudden rush of oil from the case into the

box. This is an interesting and important phenomenon. Should the machine become overloaded, the flow of oil through the relief valve is more rapid than the supply through the replenishing valve for the reason that the relief valve is acting under high pressure, while the replenishing valve is acting only under atmospheric pressure. A momentary vacuum is produced in the active body of oil, which is the same in effect as if the whole volume of oil had suddenly increased.

420. Stuffing boxes and packing.—Where the shafts pass through the cases there are stuffing boxes. These are of the ordinary type and need no special comment further than to call attention to the kind and shape of material used in packing. Leather cups of U-section are used, the U-channel being filled with pure asbestos yarn containing no paraffine, tallow, or wax filling. Two of these U-rings are used in each stuffing box. If they alone do not fill the box a sufficient quantity of asbestos yarn may be placed between the leather rings.

In the threaded surface of the control shaft bearing is a groove which is to be filled with a leather strip called the control bearing thread packing. When the bearing piece is screwed into the hanger and the control shaft bearing nut is screwed down tight, this leather strip is compressed into the channel between the top of the hanger, the nut, and the bearing so as to prevent any leakage of oil or air.

Where the end of the case fits against the valveplate, only a paper gasket is used. This is cut to fit that part of the face of the valveplate that comes in contact with the case. It is cemented onto the valveplate with a solution of shellac in alcohol.

421. Plugs.—The various plugs need only to be mentioned. In the valveplate are two gauge plugs. These close holes connected with each port passage for the attachment of pressure gauges where desired. In the cases are plugs for drainage, escape of air, equalizing pipes, etc.

HOW THE GEAR OPERATES.

422. In order that the functioning of the various parts of the machine may be understood, let us assume that the gear is assembled and filled with oil ready for running.

The entire space within the cases and valveplate not actually occupied by metal is filled with oil. No air pockets exist, and in order that no air may enter the case, the oil is made to fill the expansion box about half full. A definite portion of the oil is enclosed within the cylinders ahead of the pistons and within the port passages of the valveplate. This is the really active portion of the oil, and if there were no leakage this is all the oil that would be used in transmitting energy. The inactive oil which fills the space within the cases is never under pressure. It is simply a supply for lubrication, into which leakage from the active oil may flow and from which this leakage is replenished through the replenishing valves, the total quantity remaining constant.

With our attention directed to the A-end of the sectional views, let us first assume that the A-tilting box with its socket ring is set at the neutral position, that is, perpendicular to the shaft. Under these conditions the shaft in rotating will carry around with it the socket ring and the cylinder barrel together with the pistons and connecting rods, but the pistons will have no tendency to reciprocate in the cylinders. There will, therefore, be no drawing of the oil in or forcing it out through the valveplate. The only work done will be the stirring of the oil in the case by the revolving parts and the light friction of the shaft bearings and the sliding of the face of the cylinder barrel against the face of the valveplate. The B-end will not be disturbed.

423. If the control shaft be turned a little so as to move the top of the tilting box away from the valveplate and if the A-shaft be rotating over towards the observer, all the pistons, as they move up on the far side of the machine, will draw in oil through the port in the far side of the valveplate; all the pistons as they move down on the near side will slide in towards the valveplate and force the oil through the port in the near side of the valveplate. The near port will thus be under pressure while the far port is in suction.

It should be noticed that when a piston reaches the top or higher position, in its revolution, it for an instant makes no end movement and the oil in that particular cylinder is carried across the " Land," or space between the two valveplate ports, from the suction side to the pressure side. The same condition exists when a cylinder is passing its lowest position, except that the piston is then at the inner end of its stroke and is passing from the pressure side to the suction side.

The quantity of oil forced through the valveplate port depends upon the angle at which the tilting box stands and consequently the length of the piston stroke.

424. We have spoken of forcing the oil through the valveplate port, but this cannot take place unless there is some means acting to receive the oil and carry it across to the port that is under suction. This is the function of the B-end. The B-socket ring always stands at an angle of about 70° to the B-shaft, and when the B-shaft rotates the B-pistons will make their full stroke as they pass between the bottom and the top positions. Now, when the A-cylinders are moving down on the near side, as described above, oil is forced through the valveplate port of this side into the B-cylinders of the near side. But they cannot receive the oil unless their pistons move back to give space. This movement of the pistons communicated to the inclined socket ring through the connecting rods causes the socket ring to rotate on its roller thrust bearing, and to carry the shaft around with it. The shaft in turn rotates the cylinder barrel keyed to it, and the whole group rotates in the opposite direction to the rotation of the A-shaft.

425. The speed of rotation of the B-shaft depends upon the quantity of oil it must take care of. The B-socket ring being always set at its maximum angle gives the pistons their full stroke. If each cylinder has a capacity of say 3 cubic inches, the revolving of all nine of the B-cylinders would transfer 27 cubic inches of oil from the near side to the far side. If now the control shaft of the A-end be turned so as to tilt the A-socket ring only a little, say enough to reciprocate each piston to the extent of 1-100 of a cubic inch, all nine of the A-cylinders will together transfer 9-100 cubic inches of oil from the far side to the near side at each rotation of the shaft. Since the capacity of the B-cylinders per rotation of the B-shaft is 27 cubic inches, 300 rotations of the A-shaft will be necessary to rotate the B-shaft once. If the A-socket ring be tilted still further, the B-shaft must rotate proportionately faster. The speed of the B-shaft is thus dependent upon the angle through which the control shaft has been turned.

426. We have thus far spoken of the A-socket ring as tilted in one direction only. If it be tilted in the opposite direction, that is, with the top towards the valveplate, and the A-shaft still rotates in the same direction as before, the oil will be sucked in from the

near port of the valveplate and carried under across the lower land to the far side. This will, of course, cause the B-shaft to rotate opposite to its former direction, that is, in the same direction as the A-shaft.

The Oil Pressure.

The pressure of the oil in the valveplate passage depends upon the resistance offered to the turning of the B-shaft and not upon the speed. The pressure rises instantly to meet any resistance up to the capacity of the driving motor. If the A-socket ring stands almost perpendicular to the shaft, only a very small quantity of oil is transferred per rotation, which has the effect of giving a very great leverage, and even a small motor may produce a pressure of several hundred pounds, and, of course, a corresponding torque or turning effort on the B-shaft. The actually permissible pressure in any particular machine depends upon the strength of the parts, but is limited by the setting of the relief valves.

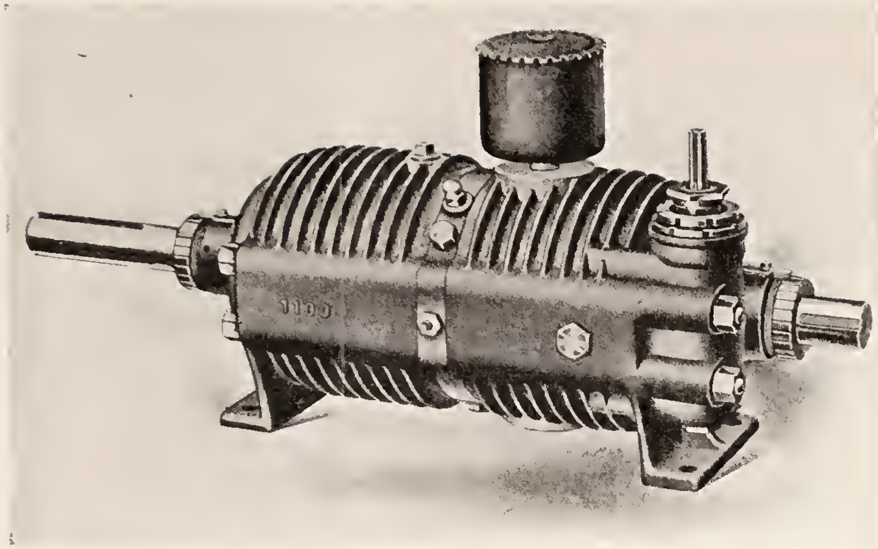


FIG. 1.—Exterior View.

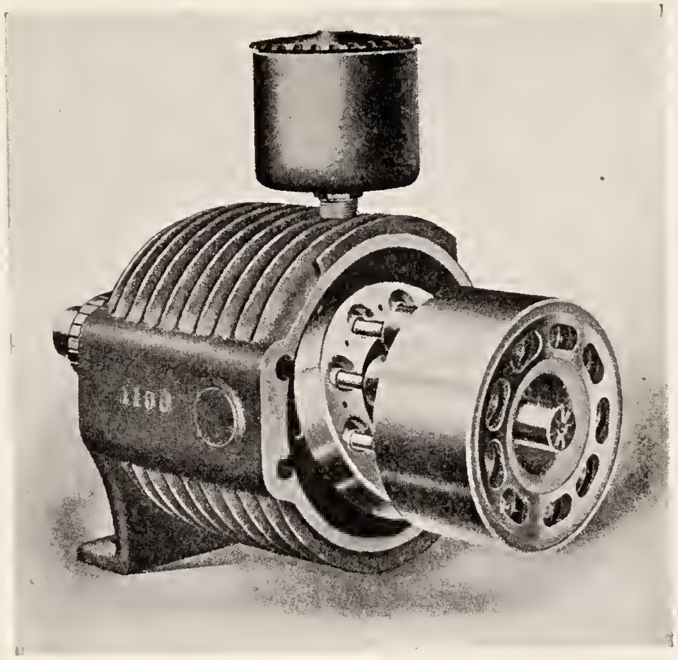


FIG. 3.—B End, with B Shaft Group.

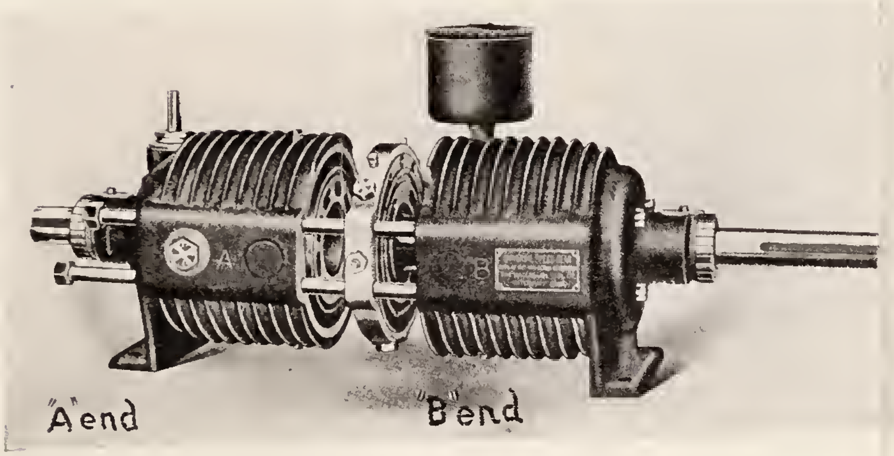


FIG. 2.—The Two Ends Partly Separated.

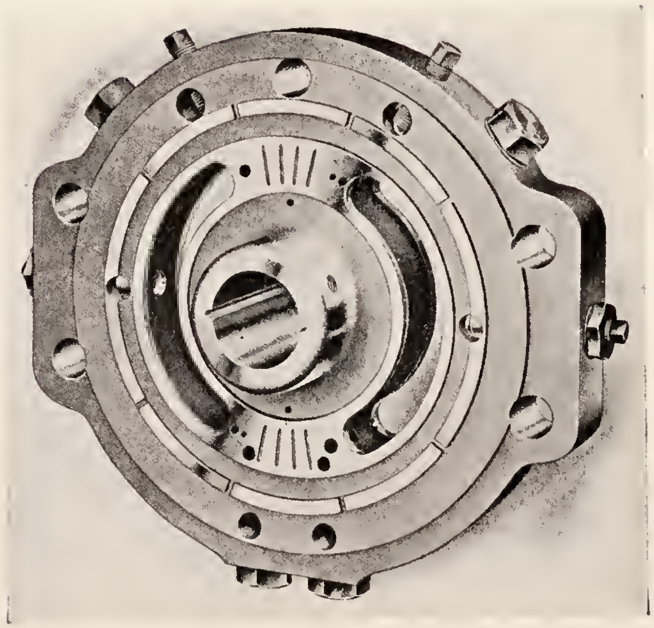


FIG. 5.—Midplate or Valveplate. (Showing the A Face.)

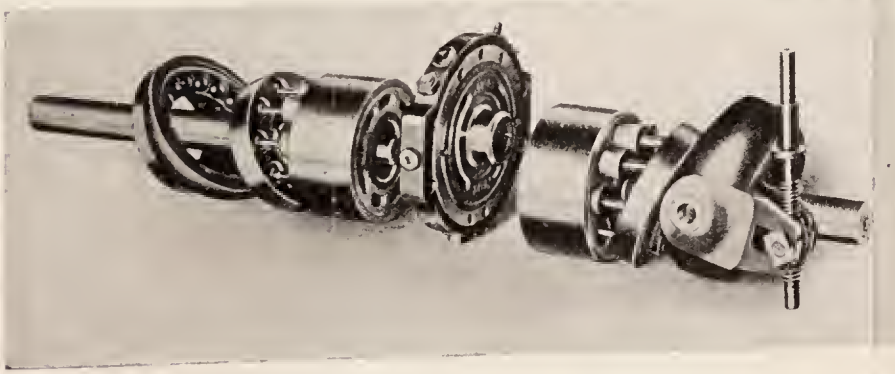


FIG. 4.—Internal Parts.

THE UNIVERSAL SPEED GEAR, TYPE C.

SECTIONAL PLAN

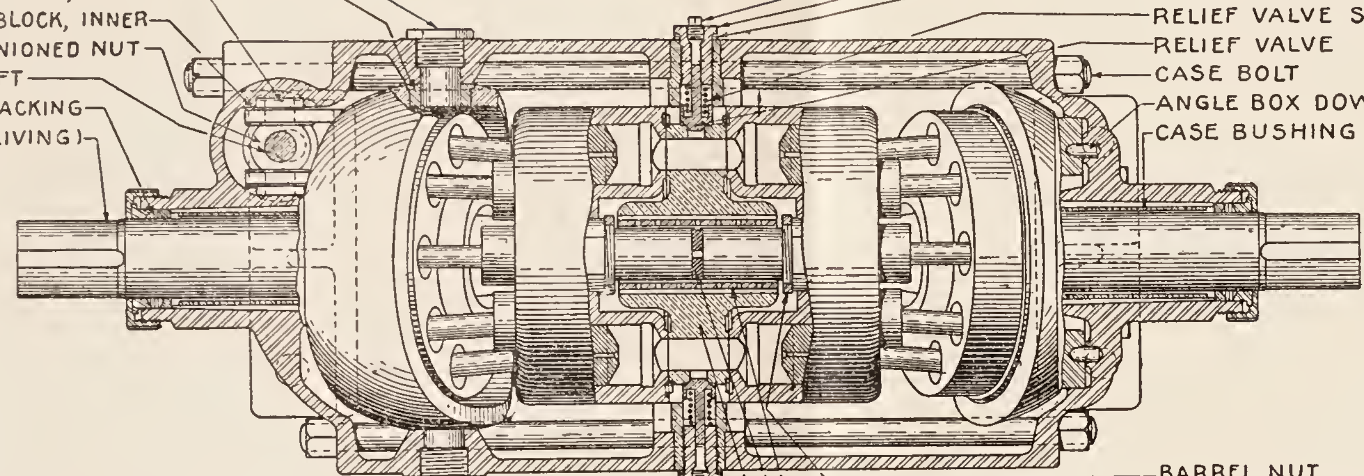
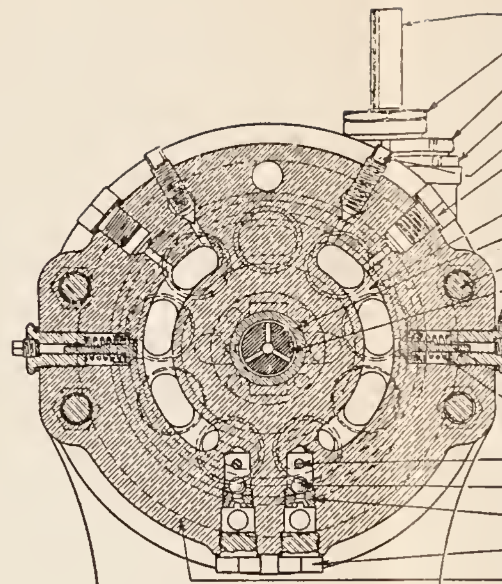


FIG. 1



TRANSVERSE SECTION OF MIDPLATE.

FIG. 3

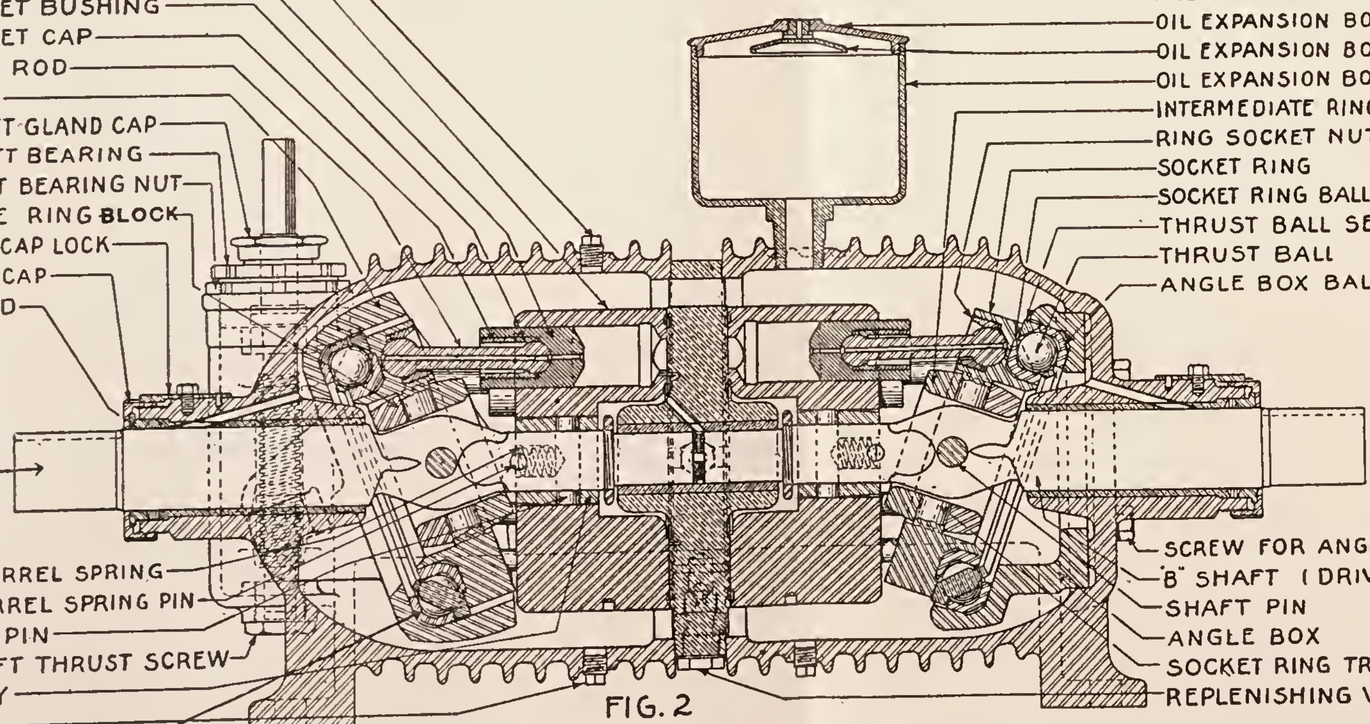
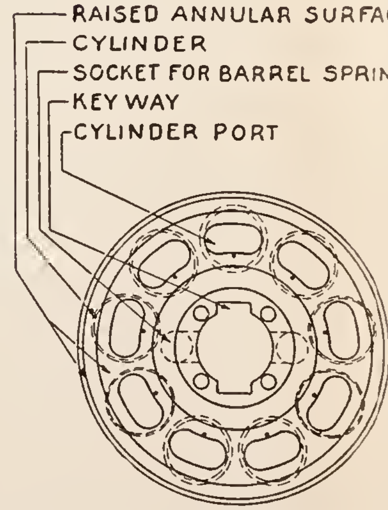
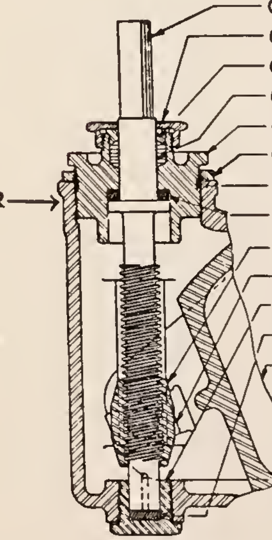


FIG. 2
SECTIONAL ELEVATION



"A" CYLINDER BARREL AS SEEN FROM MIDPLATE.

FIG. 4



SCREW AND NUT TYPE OF CONTROL SHAFT

FIG. 5

THE UNIVERSAL SPEED GEAR.

CHAPTER XI.

BREECH MECHANISMS.

427. Definition.—A *breech mechanism* is a mechanical device for closing the rear end of the chamber or bore of a breech-loading gun. The term includes the breech block or plug, all mechanism contained in or with it, and necessary operating gear.

428. Requirements for a breech mechanism.—The following may be said to be the principal requirements for a successful breech mechanism:

1. **Safety.**—To be safe: (a) The gas must be prevented from escaping to the rear; this sealing, or obturation, must be automatic, greater pressure increasing the sealing or obturation. (b) The breech of the gun must not be weakened by the fitting of the breech mechanism. (c) The parts must have ample strength to prevent any portion from being broken or blown to the rear. (d) The danger of premature discharge must be minimized. (e) The breech block must be securely locked to prevent opening on firing.

2. **Ease and rapidity of working.**—This is necessary for rapid and continuous fire. Hence, this should include facility of loading, and certainty of extraction for rapid-fire guns.

3. **Not easily put out of order.**—In other words, it must be able to meet service conditions and hard usage. Parts should have a reserve of strength. All parts of the mechanism should be so designed as to be protected against injury.

4. **Ease of repair.**—Parts most exposed to wear should be so designed as to permit being easily replaced. This should also include accessibility of parts, so that breakage of any part will not disable the mechanism for any length of time.

5. **Interchangeability.**—Not only should individual parts be made interchangeable by accurate workmanship, but the whole mechanism should be capable of being mounted on similar guns. This is necessary to meet service conditions.

429. The breech block or plug is the movable piece closing the breech of a gun. In most built-up guns it is carried by the jacket;

in the latest large guns, however, it is carried within a screw-box liner, or bushing. The above term applies to any shape of piece, or for any system of closure.

430. In small arms and certain special guns, the term breech "bolt" is often used, instead of "plug" or "block," and "breech action" is a better term in this case than "breech mechanism."

431. Systems of breech mechanism.—There are six principal systems of breech blocks in use, viz.: (1) *The interrupted screw,* (2) *vertical sliding wedge,* (3) *horizontal sliding wedge,* (4) *combined sliding and rotary system,* (5) *rotating eccentric block,* and (6) *the sliding-bolt system.*

432. The interrupted-screw system is, in general, used in the navy for all guns of and above 3 inches in caliber. Secondary rapid-fire guns use systems (2), (3) and (4). Rotating eccentric blocks (5) are used by the navy for cartridge case guns. Military rifles, as well as certain automatic guns and machine guns, generally, use the sliding-bolt system.

433. Special guns, such as automatic guns, machine guns, etc., more properly use a "breech action," in which the different steps in closing the breech and operating the entire mechanism are very intimately connected. The system in these cases is defined by the name of the gun.

434. The interrupted-screw system, also called "slotted screw," is divided into three classes: (1) French interrupted screw; (2) Elswick interrupted screw; and (3) Welin interrupted screw.

435. In general, an interrupted screw plug is a plug which has two or more sections of the thread removed in the direction of the axis. Similar interruptions are made in the female thread of the screw box in the gun, in order that the plug may be entered or withdrawn in one motion and only a portion of a turn be given to lock or unlock the same in the screw box.

436. The French interrupted screw was the most common system of fermeture, and was long in use. The breech plug, cylindrical in shape, has cut on its circumference a male thread, the character of which varies according to particular designs. It is then divided into a number of equal sections in the longitudinal direction (always divisible by two; usually six, eight or twelve), and the threads of alternate sections are then planed or slotted out. The female thread in the screw box is similarly slotted. In

closing the breech, the threaded sections of the plug are brought opposite to the blank sections of the screw box; the plug is pushed in either by hand, or by some mechanism, to the proper distance; and a fraction of a turn to the right or left is given, to interlock the threaded sections, the amount of turn necessary depending upon the number of threaded sections. Six threaded sections require 60°; eight divisions, 45°, etc. The system is independent of the method of operating the mechanism.

437. **The Elswick interrupted screw** differs from the French type, in that the forward part of the plug is conical and the rear part cylindrical. The threaded sections of the coned portion and the threaded sections of the cylindrical part are staggered. The advantages claimed for this arrangement are: (1) The working of the mechanism is facilitated, as the plug can be swung clear of the screw box without translation; (2) arrangement of the threaded sections distributes the strain around the entire circumference of the plug; (3) the cone-shaped plug increases the cross-section of the jacket at the forward end of the plug where the stresses in the gun are greatest.

438. **The Welin interrupted screw** or *"stepped-thread"* system has the block divided circumferentially into a number of groups of blanks and threaded sectors of increasing radius, so disposed that when the plug is unlocked the smaller threaded sectors of the plug clear the larger threaded sectors of the screw box. Each group of sectors consists of one blank and two or more threaded sectors. Three or four such groups of sectors are arranged around the circumference of the plug. This arrangement of threads gives a larger percentage of threads for a given length of plug and results in a lighter and stronger plug.

439. **The vertical sliding-wedge system,** exemplified in the Hotchkiss and 3-inch semi-automatic guns has a rectangular wedge-shaped block (containing the firing mechanism) that slides up and down in a vertical mortise within the square-shaped breech of the gun, guided by vertical ribs. It is moved by means of a crank, journaled in the right cheek of the mortise; a stud on the other end of the crank moves in a cam groove in the side of the block. The wedge completely closes the mortise when up, and gives only a sliding movement to the cartridge case in shoving it home.

440. The horizontal sliding-wedge mechanism is similar to the vertical sliding-wedge system except the block moves in a horizontal direction.

441. The combined rotary and sliding-wedge system is exemplified in our service in the Nordenfelt 6-pounder and 3-pounder rapid-fire guns only. The breech block may be said to consist of two parts, the block and the wedge, the latter sliding on the front face of the former in the locking or unlocking movement; while to cover or uncover the bore, both rotate about a transverse axis, the top falling to the rear in opening.

442. The sliding and rotary-block system.—In this system, to open the mechanism the block slides downward and is then rotated on a transverse axis, the upper part falling to the rear. This system is exemplified in our service by the Driggs-Schroeder guns. It has a rectangular block with rounded top, working entirely within the breech housing and is locked by means of collars on top of the block engaging corresponding grooves in the housing. The grooves are inclined slightly to the front, so the final movement in closing is upward and to the front, pushing home the cartridge case. The operation is through a cam within the block, moving against curved surfaces in the block's recess: The cam is moved by a transverse axis.

443. The sliding-bolt system.—In this system a more or less cylindrical piece, containing at least the firing pin and spring or hammer, moves longitudinally in a "receiver" attached to the gun barrel, and may be worked either by hand, as for small-arm rifles, or by certain mechanism, as in the Colt automatic gun. The bolt may have only a direct movement to the rear and front, giving the name "straight pull," or have a part attached which is turned for locking or unlocking, giving the name of "turn bolt."

444. Types of ordinary systems of breech operation.—There are four types: (1) *Service;* (2) *modified Farçot;* (3) *improved Farçot;* (4) *Naval Gun Factory design.* The difference between (2) and (3) is so slight that it is usual to class both under (2).

445. Types of quick-acting breech systems: There are five principal types: (1) *Rapid fire;* (2) *semi-automatic rapid fire;* (3) *automatic rapid fire;* (4) *quick fire;* and (5) *machine gun.*

446. A rapid-fire breech mechanism is a quick-acting one, without a gas check. It is provided with an extractor and special

firing mechanism for use in guns using a primed metallic cartridge case, or, in other words, for case guns. (See paragraph 156.)

447. A quick-fire breech mechanism is a quick-acting one provided with a gas check and a firing lock for use on guns where the charge is put up in bags and not in a metallic case, or, in other words, when loaded in bag guns. (See paragraph 155.)

448. There is, in reality, no distinction between the rapid fire and the quick fire, so far as the operating gear is concerned; but the name is given because the guns differ in their ammuntion, or rather in the manner of putting up the same. The breech mechanism differs, no extractor being necessary for the latter, but a firing lock is necessary.

The term "quick fire" is apparently indiscriminately used abroad for guns having a quick-acting mechanism, whether using metallic cartridge case or powder charges in bags. It is well that a distinction should be made, as in the U. S. Navy, by the use of the terms "case guns" and "bag guns."

449. Semi-automatic rapid-fire breech mechanisms are quick acting, part of the operation being by hand and part automatic. This gives rise to the name, both as "rapid fire" and as "semi-automatic."

450. Automatic rapid-fire breech mechanisms are those in which all the operations are performed automatically by utilizing the energy of recoil. The name also defines the gun.

The breech actions of machine guns are essentially quick acting, and their special features are the distinctive features of the gun.

Systems of Gas Checks.

451. Gas check.—This is a device to prevent the escape of the powder gas to the rear around the breech block or through the vent.

452. The following are the **principal characteristics** governing the design of a gas check:

1. It should function at all temperatures that may be encountered in service due to weather conditions, that is, from approximately 5° to 110° F., and also be unaffected by the variations in temperature due to firing the gun. Temperature rises as high as 200° F. have been observed when firing a 3-inch rapid-fire gun.

2. The device should not adhere too strongly to its seat in order that the mechanism will function with ease.

3. It should be elastic enough to conform to its seat, but also rigid enough so as not to be deformed to such an extent as to prevent successive functioning.

4. It should respond equally as well to the lowest as to the highest pressure developed in the gun.

5. It should exert a pressure on its seat greater than, or at least equal to, the gas pressure.

To meet the above requirements it is necessary to consider, first, the type, and second, the application of the gas check.

453. There are in general two types of gas checks, the *plastic* and the *elastic*.

454. The advantage of the *plastic gas check* is that it conforms to any irregularities of its seat caused by erosion or accident.

The disadvantages are the fact that it is apt to adhere to its seat too strongly, or to be deformed while the block is open with the result that the mechanism will not function with ease. Plastic materials do not possess a definite form, but conform easily under pressure to their seats. The pressure is transmitted equally in all directions, as in a fluid, and, to a greater degree than in elastic solids.

The first plastic materials used for gas checks were fibrous materials such as cardboard or papier-mâché. Experiments were also made with soap, but the soap liquefied due to the action of the heat.

The materials actually in use are composed of about 65 per cent of a mineral fiber such as asbestos, and 35 per cent of tallow. The tallow keeps the gas check plastic and causes the fiber to flow under the action of the heat and pressure.

455. An elastic gas check conforms to its seat under pressure except when small irregularities exist in the surface of the gas-check seat, hence the sealing depends upon the condition of the surfaces in contact. On the other hand, there is less tendency to adhere to its seat as the device returns to its original form as soon as the pressure is relieved, and it is not so easily deformed when the block is open.

Elastic material may be divided into two classes, rigid and flexible, depending upon the resistance they offer to deformation. Steel is the most rigid and rubber compounds are the most flexible materials that have been used.

FIG. 1. INTERRUPTED SCREW.
ALL MAIN BATTERIES.
4" PLUG.

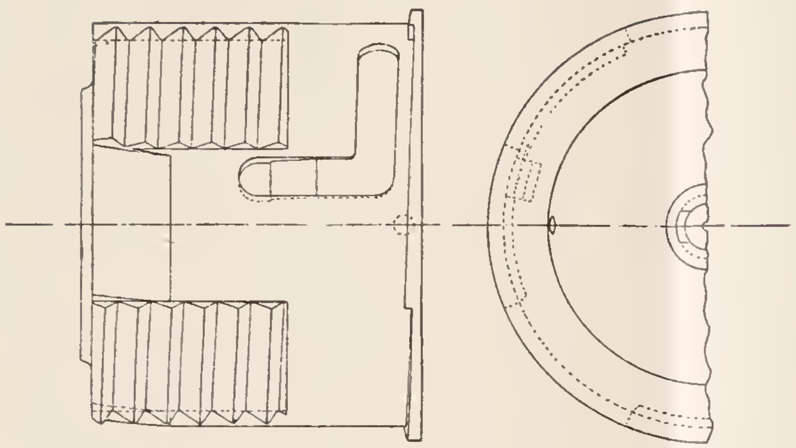


FIG. 2. SLIDING WEDGE.
HOTCHKISS 6-PDR.

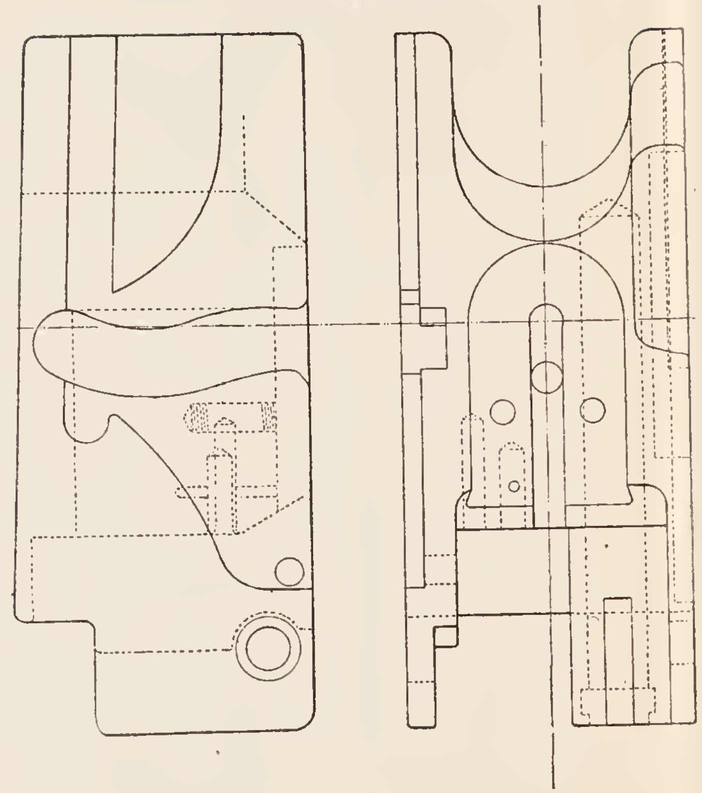


FIG. 3. SLIDING AND ROTARY BLOCK.
DRIGGS-SCHROEDER 6-PDR.

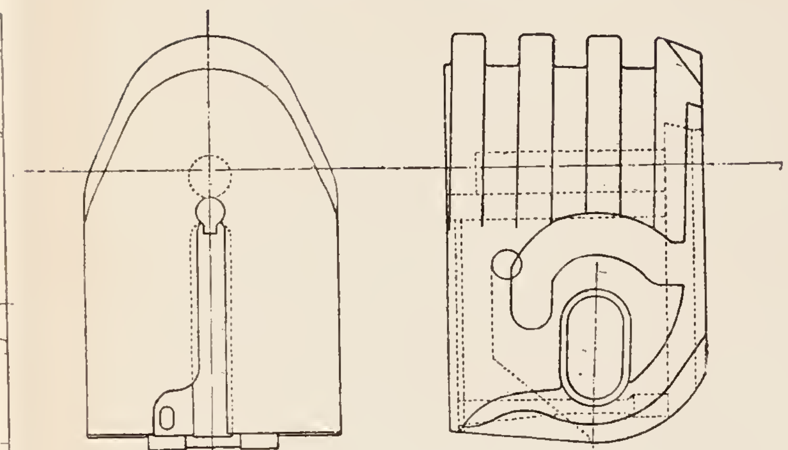
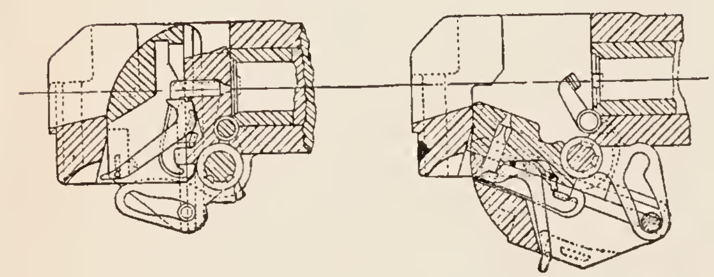


FIG. 4. COMBINED ROTARY AND SLIDING WEDGE.
NORDENFELT 6-PDR.



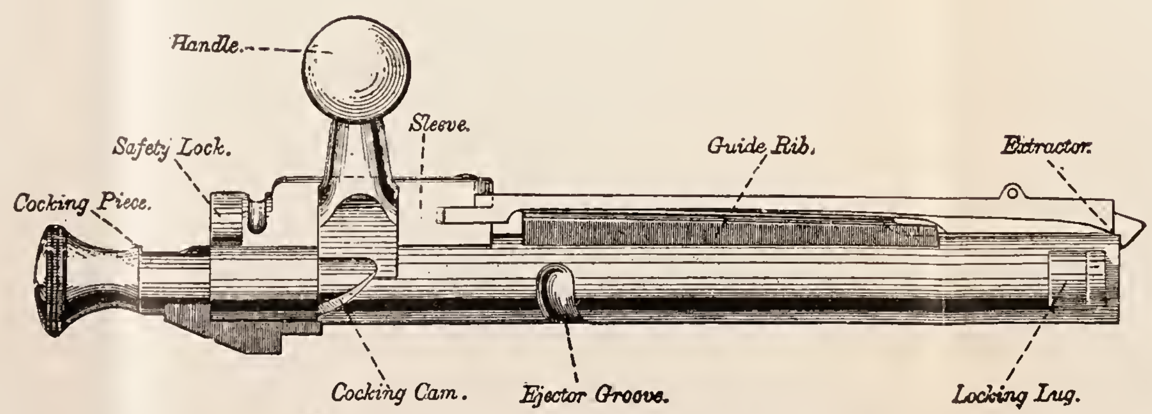


FIG. 5. SLIDING BOLT SYSTEM. U. S. MAGAZINE RIFLE.

SYSTEMS OF BREECH-BLOCKS.

FIG. 1 FRENCH INTERRUPTED SCREW.

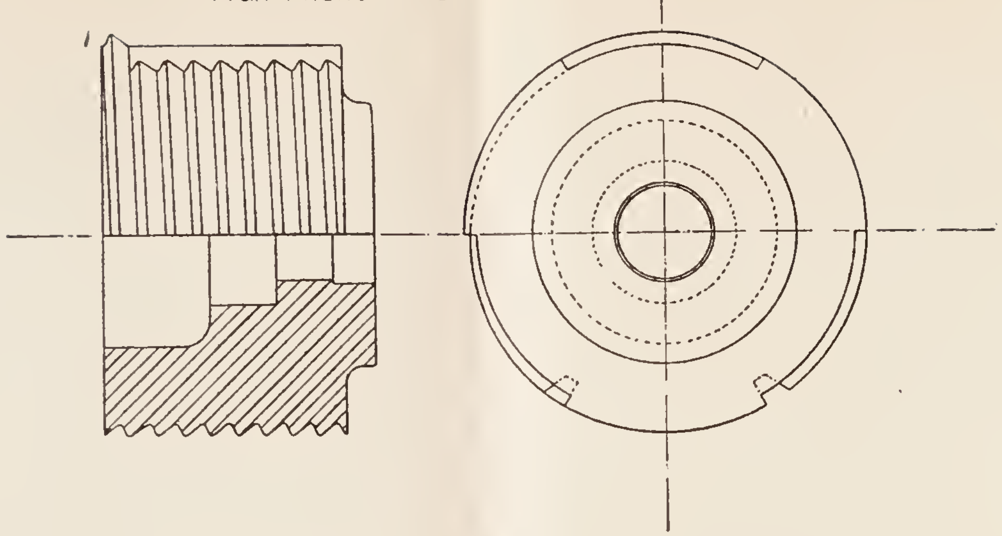


FIG. 2 ELSWICK INTERRUPTED SCREW.

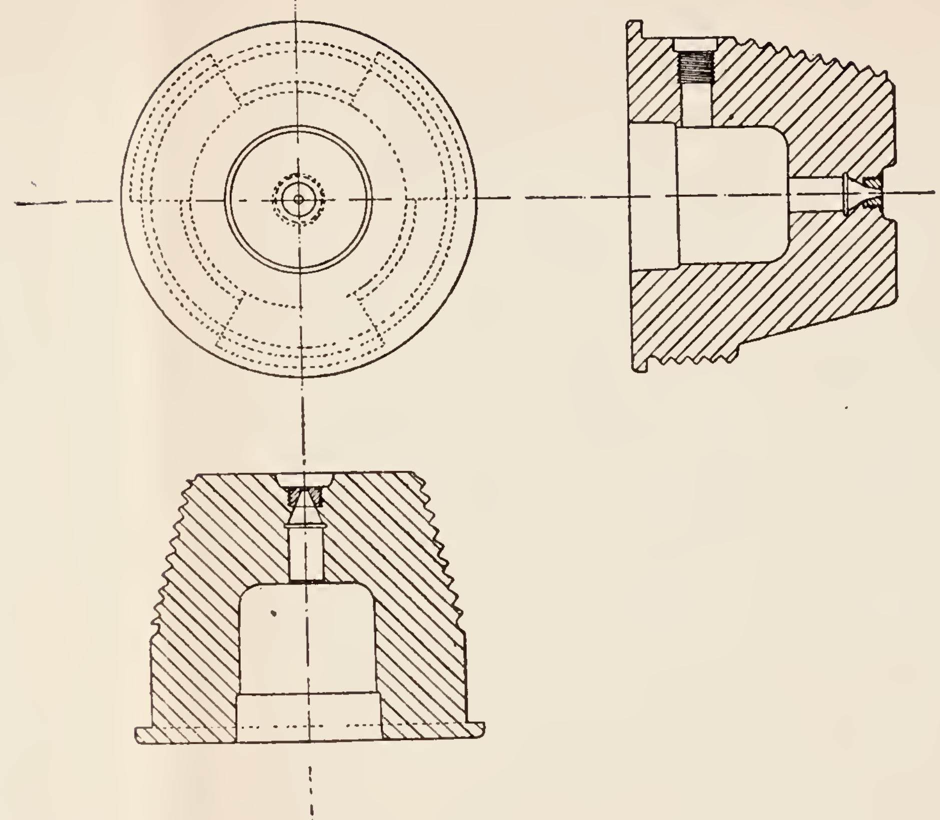
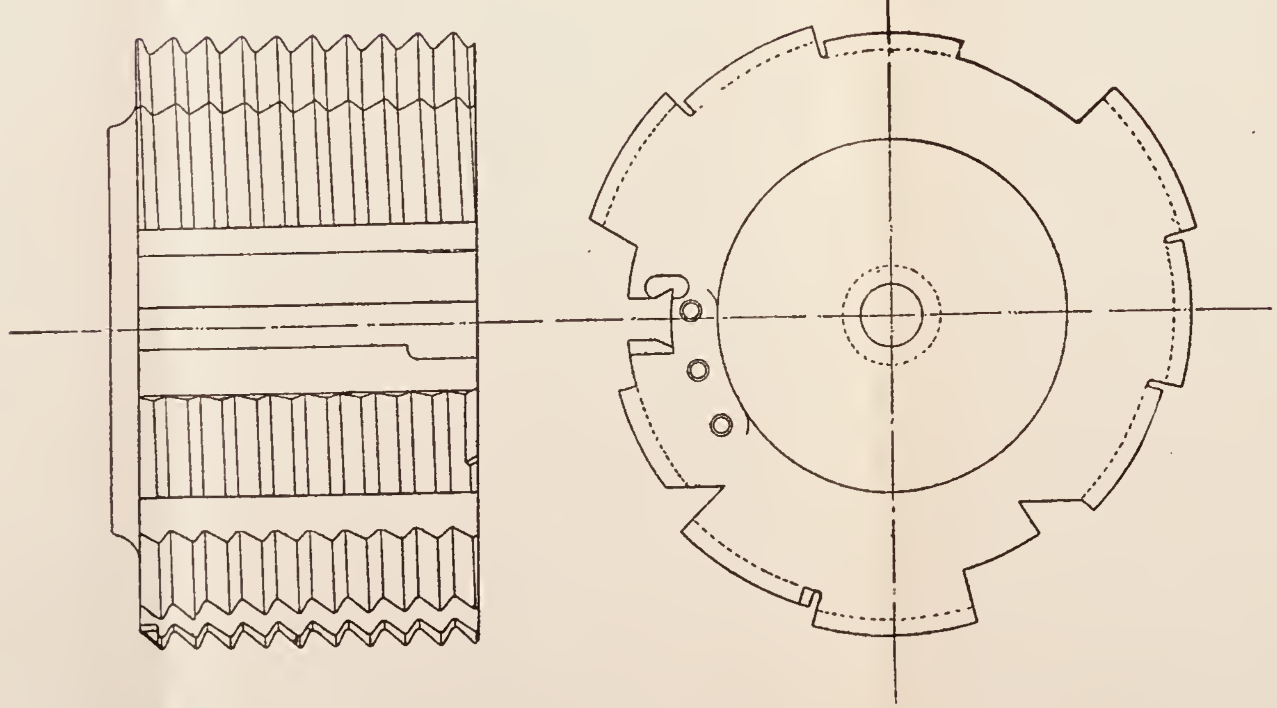


FIG. 3. WELIN INTERRUPTED SCREW.



THREE SYSTEMS OF INTERRUPTED-SCREW THREAD.

Rubber compounds give a good seal for a few rounds, as they conform easily to their seats, but they are apt to adhere to the gun or block which makes it difficult to operate the breech mechanism. They are sensible to variations in temperature, being too soft at high and too hard at low temperatures. They are also attacked by the powder gas and oil. Elastic gas checks are made of copper, brass or steel.

456. The methods of applying gas checks may be divided into three types:

1. Gas checks sealed by having an initial pressure on their seats.

2. Gas checks in which the pressure on the seat is built up automatically by the pressure of the powder gas.

3. Gas checks with an initial pressure on their seats but which pressure is increased by the action of the powder gas.

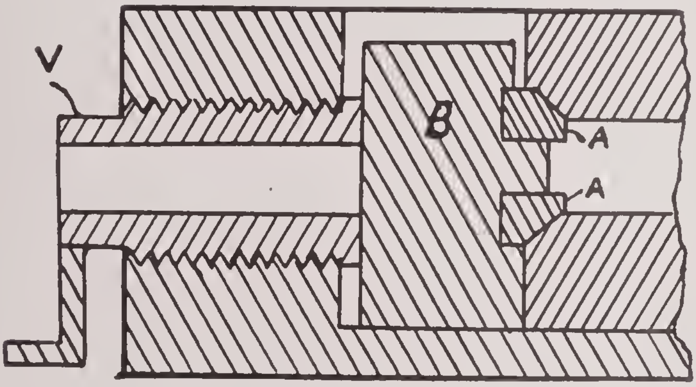


FIG. 63.

457. Type 1. The Armstrong gas check, Fig. 63, is an example of this class. *AA* is the gas check, *B* the block, and *V* a screw device for putting the initial pressure on the gas-check seats.

The disadvantages of this gas check are due to the following: The gas check should be made of a material softer than its seat in order that it will conform to it, and it should be pressed against its seat with a pressure high enough to prevent the gas from escaping, as the action of the gas is to open the joint. On the other hand, the gas check should be hard enough so as not to be permanently crushed by the pressure of the gas. These are opposite characteristics and in reality the sealing of this device is poor and it is no longer in use.

458. Type 2. Automatic sealing.

There are two methods of automatic sealing: by expansion, and by compression.

(A) *Sealing by expansion* is obtained by the use of a metal cartridge case, Fig. 64. The action of the gas is to expand the cartridge case against the wall of the chamber of the gun. The amount of this expansion being equal to the clearance between the case and chamber, plus the deformation of the gun due to the pressure of the powder gas. The total expansion should not exceed the elastic expansion of the case, as otherwise the case may be permanently deformed or cracked and offer too much resistance to ejection. For this reason the metal should not be too hard or too soft.

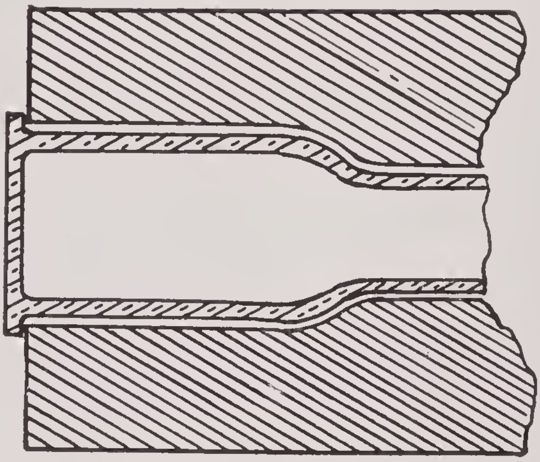


FIG. 64.

When the charge is first ignited a small quantity of gas passes between the case and the wall of the chamber, but due to the small area and length of the channel, the resistance to its passage is high, and the pressure builds up so rapidly in the case that the sealing takes place very quickly. The surface in contact is so large that small local irregularities do not effect the seal.

The case should be sufficiently thick at the base to prevent the metal from being forced into the joint between the breech block and the gun, but sufficiently thin at the mouth to insure easy expansion.

(B) *Sealing by compression* is generally obtained by the use of a plastic gas check as in the de Bange system (Fig. 65). A pad of

plastic material, A, contained in an envelope, B, is held between the breech block, C, and the "mushroom," D, by the spindle of the mushroom which passes through the pad and breech block.

The action of the gas pressure is to force the head of the mushroom to the rear, thus building up a pressure in the plastic material which is transmitted in all directions and presses the envelope against the wall of the gun.

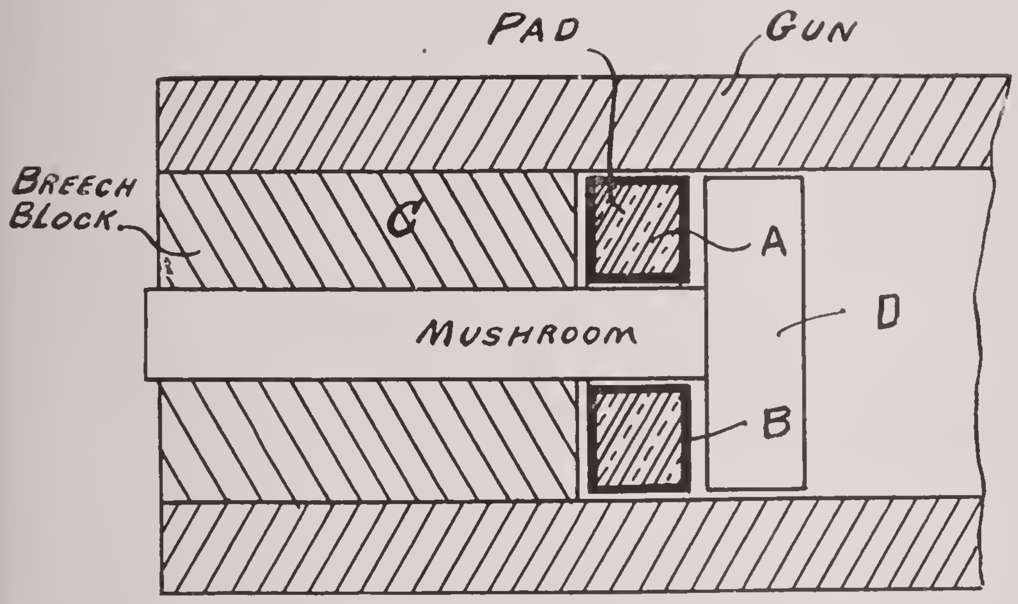


FIG. 65.

Let A = the area of the front surface of the head of the mushroom.

A' = the area of the cross-section of the spindle.

P = the gas pressure.

P' = pressure on the seat of gas check.

N = a constant depending upon the plasticity of the gas check. The value of N for a fluid being 1.

Then

$$P' = \frac{NPA}{A - N'}.$$

The values of N, and A, are made such that P', will be somewhat greater than P.

459. Plastic gas checks function very well when the gun is not fired too rapidly and with proper care a large number of rounds may be fired without changing the pad. On the other hand they are heavy and offer more or less difficulty to the installation of the firing mechanism and its safety features.

460. *The pads* are made of a plastic material with a neat-fitting canvas cover. The edges are protected by split metal rings which expand due to the pressure transmitted by the pad. In some cases the front and rear faces of the pads are protected by metal discs.

When the pads are to be used in guns where high pressures are developed, the pads are made as above except they are compressed in steel dies under a pressure from 50,000 to 80,000 pounds per square inch. After being subjected to this pressure they are no longer soft but possess a certain amount of elasticity, and may be said to be plastic-elastic. Due to this initial compression the recoil of the mushroom relative to the breech block is very small.

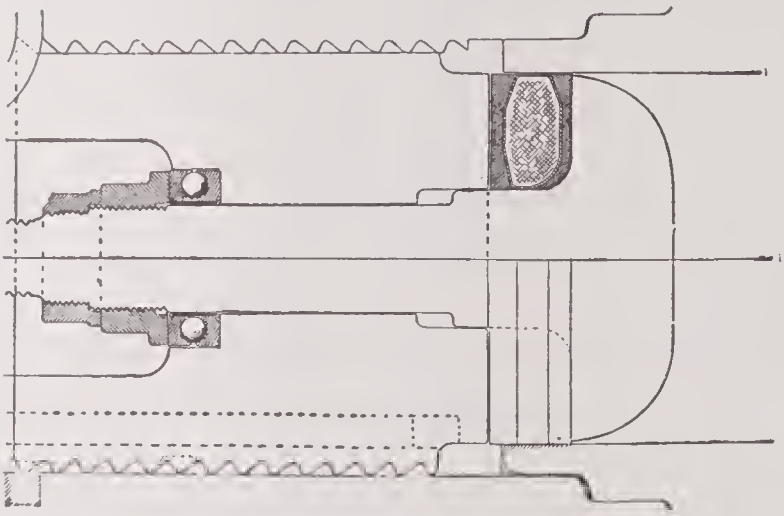


FIG. 66.—THE DE BANGE GAS CHECK, WITH DISKS.

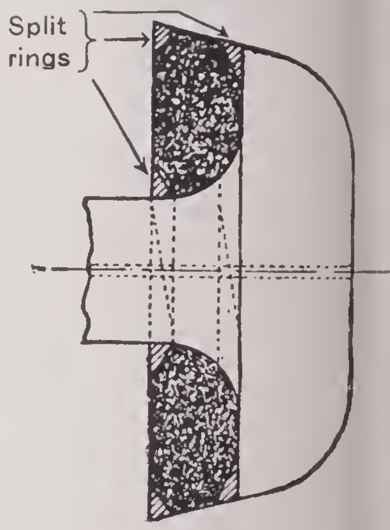


FIG. 67.—THE DE BANGE GAS CHECK (Later form, showing split-rings.)

Figs. 66 and 67 show the types of De Bange gas check used in the navy.

461. To this group may be added the system shown in Fig. 68 and experimented with in Spain.

This system consists of a mushroom, *A*, which bears against a copper ring, *B*, of triangular cross-section. The pressure of the powder gas on the mushroom head causes the copper ring to expand and exert a pressure on its seats. It appears that this system should give good results.

462. Type 3. Gas checks with initial and automatic seal:

In general, these gas checks (see Fig. 69) consist of a metal ring, *B*, adjusted to suit its seat in the chamber, with the diam-

eters of the ring slightly larger than those of its seat. By closing the block, the ring is forced to bear against its seat with a certain initial pressure. The profile of the ring is such that the pressure of the gas tends to press it against its seat. If it were not for the initial pressure, the pressure of the ring on its seat would be at

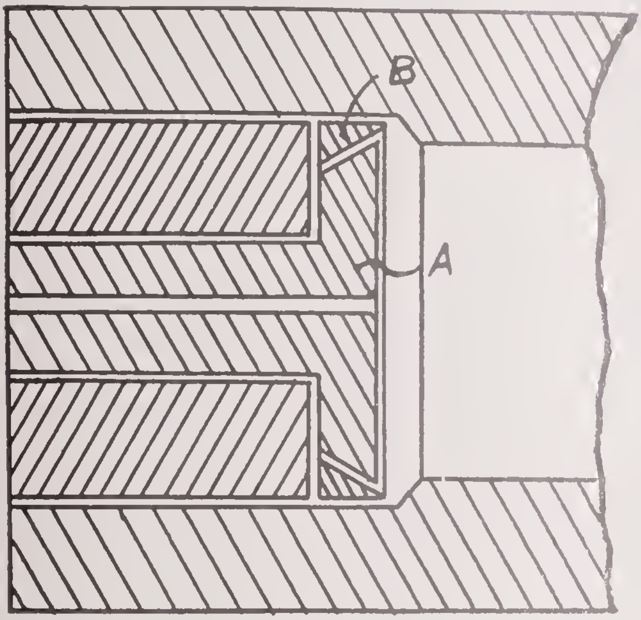


FIG. 68.

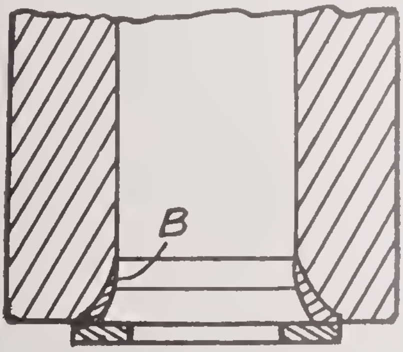


FIG. 69.

most only equal to the pressure of the gas, and gas would be apt to escape. With the pressure due to the gas added to the initial pressure, a seal is affected.

The trouble with the above type of gas check is due to the difficulty experienced in adjusting the rings and making repairs due to erosion, which might result in the escape of gas. It is also

necessary to wash the rings frequently. The surface of the breech block, subjected to pressure, is increased, being equal to the area of a circle whose radius equals the radius of the gas-check seat. This radius is larger than the radius of the chamber. On the other hand, this check is light and does not take up much space in the gun, and lends itself easily to the installation of the firing mechanism with its safety features.

Gas checks with initial and automatic seal may be divided into two sub-groups, those attached to the breech block, and those attached to the gun.

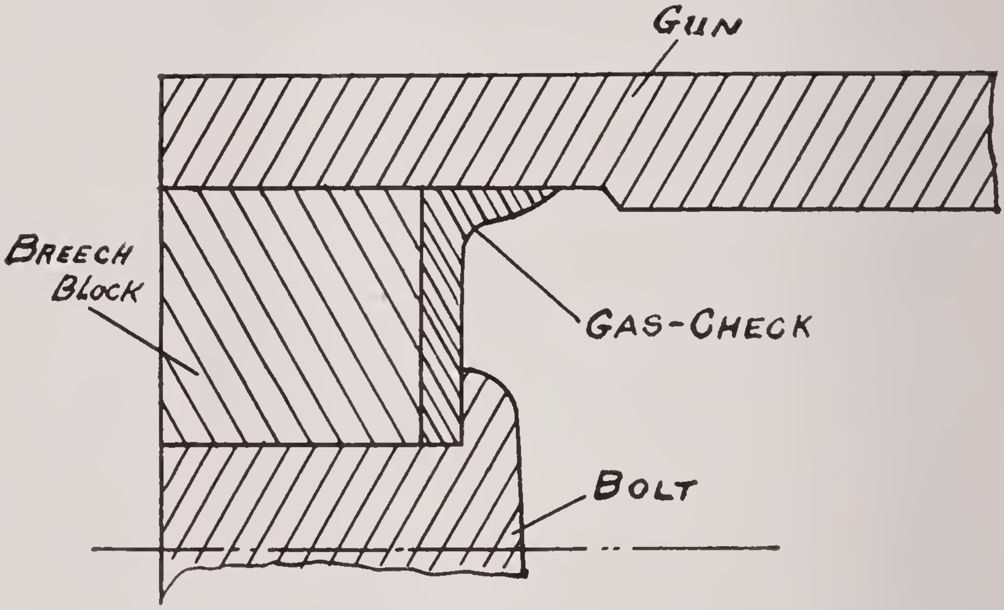


FIG. 70.

The first gas checks of this type were attached to the breech block in such a manner that they might be removed for cleaning and repairing, when necessary.

The gas checks of older model French naval guns consisted of a steel gasket, Fig. 70 held to the breech block by a bolt passing through the center of the gasket. The part of the chamber forming the seat was bored with a taper, the diameter at *B*, being slightly smaller than the diameter of the gas check which produced an initial pressure when the block was closed. The pressure developed in the gun held the gasket pressed against the breech block and expanded the flange against the seat. The front edge of the flange was chambered to facilitate the expansion and lessen the adherence.

In the older breech loading German guns the gas check consisted of a steel ring of triangular cross section, Fig. 71. The ring was placed in the breech block with the inclined surface to the rear; the pressure of the gas on the inclined face sealed the joint at *b*.

The disadvantage of this type is that the gas check is apt to be damaged when the block is open, and its use has been almost completely discontinued.

463. Actually, gas checks of the initial and automatic sealing system are, in general, attached to the guns; the first type used being the broadwell ring.

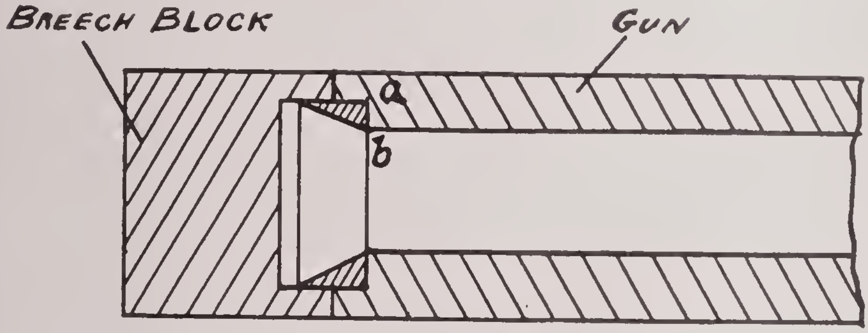


FIG. 71.

This consists of a ring of copper fixed in a seat machined in the powder chamber of the gun, Fig. 72. The diameter of the ring being a little larger than the diameter of its seat. When the breech block is closed this ring is seated with an initial pressure against a ring of the same metal fitted into the breech block. The initial seal is due to the pitch of the thread of the breech block. As the surface of the ring *a*, is very much less than the surface subjected to pressure of the gas check, the obturation is secured. The copper not being supple, expansion grooves are cut in the surface of the gas check and supporting ring, Fig. 73. If the gas escapes into the first groove it will expand with a drop in pressure and be less apt to escape to the second. Gas seldom escapes past this gas check when it is properly placed in its seat.

464. Mechanism for breaking the seal of gas checks and extracting cartridge cases:

Gas checks tend to adhere strongly to their seats after guns have been fired and it is necessary to provide a special mechanism to loosen them before opening the breech.

When cartridge cases are used it is necessary to provide a mechanism for extracting the case. This mechanism should be designed, first, to loosen the case by extraction, and second, to eject the case when the breech is fully open.

With a gas check of the broadwell ring type, the adherence of the gas check after the gun has been fired is of a low order, and a large part of the initial effort necessary to start the opening of the breech mechanism is due to the adherence of the threads of the breech block, and not the adherence of the gas check. This is an appreciable advantage of this type of gas check.

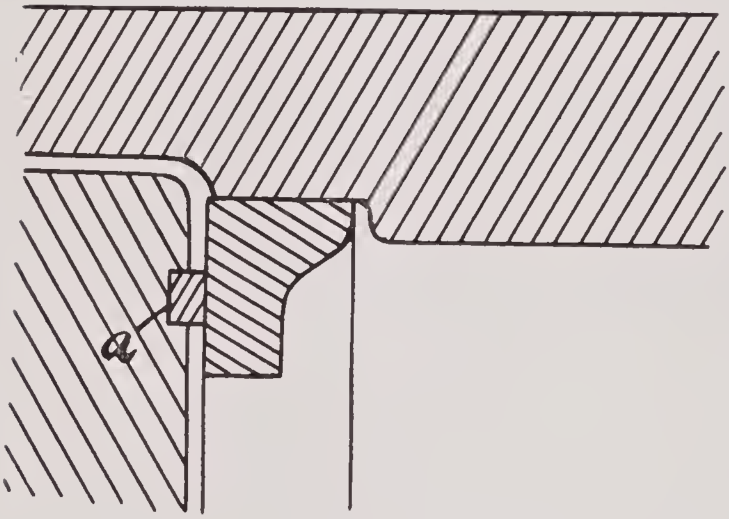


FIG. 72.

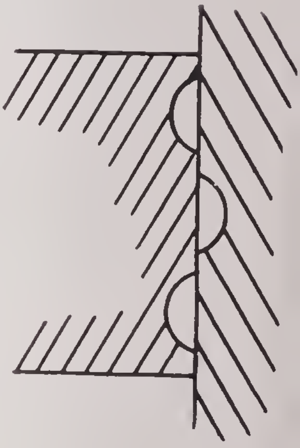


FIG. 73.

When plastic gas checks are used it is necessary that the breech mechanism be designed so as to facilitate the breaking of the seal of the gas checks, which adhere strongly to their seats after the gun has been fired. In the first place it is necessary that the breech block may be rotated independently of the gas check, and secondly, that sufficient force may be exerted to translate the block and gas check to the rear.

In the De Bange system the breaking of the seal is accomplished by passing the spindle of the mushroom through the breech block and placing a collar on the rear end of the spindle. A ball bearing is placed between the collar and the breech block (see Fig. 66). This arrangement permits the block to rotate without turning the gas check, but the collar causes the gas check to translate with the block, due to the pitch of the thread on the breech block.

In some cases a spiral spring is also placed between the collar on the spindle and the breech block. This spring permits the breech block to be translated slightly as well as to be rotated independently of the gas check. The compression of the spring is limited by a shoulder on the collar. The force tending to break the seal is increased as the spring is compressed, and should the adherence be strong enough to hold until the shoulder on the collar comes into contact with the breech block, the seal will be broken as a force will build up quickly between the collar on the spindle and the breech block, due to the fact that the latter will be in motion.

465. Extraction.—The design of mechanisms to extract and eject cartridge cases varies with the particular design of the breech mechanism, but, in general, it consists of a lever which engages the rim on the cartridge case. This lever remains stationary during the first part of the rotation of the block, the portion which engages the case is then moved slowly to the rear by means of a lever arm or cam surface which causes sufficient force to be exerted on the case to start it from its seat. The lever then becomes practically stationary until the breech is fully open; then the lever is given a very quick motion to the rear with the result that the case is ejected clear of the gun.

466. Locking the breech mechanism to prevent opening due to the shock of firing:

Breech mechanisms in general cannot be opened by a pressure on the front face of the breech block, but there is a tendency for the breech mechanism to open, due to the shock of firing, and it is necessary to provide some form of positive lock. The design of these locks varies with the particular mechanism, but usually the lock feature is incorporated in the operating mechanism. The operating handle is latched in the closed position by the "salvo latch" which unlatches during the recoil of the gun. The salvo latch prevents the mechanism from being open after the gun has been loaded except when done so deliberately and with full knowledge that the gun is loaded.

Firing Mechanisms.

467. Definition.—The term "firing mechanism" is used to designate that part of the breech mechanism which directly explodes the primer and thus fires the gun.

468. Guns are fired by *percussion* and by *electricity*. Percussion primers are used for guns of 3-inch caliber and below, while guns of larger caliber use combination primers which may be fired either by percussion or by electric current. For large guns electric firing is considered preferable, percussion firing being used only as an alternative.

Current for electric firing is furnished by batteries or by motor generators, connections being made so that either may be used as desired.

469. Definition of percussion and electric firing mechanism.—A percussion firing mechanism is one in which the blow of a firing pin explodes the cap in a primer.

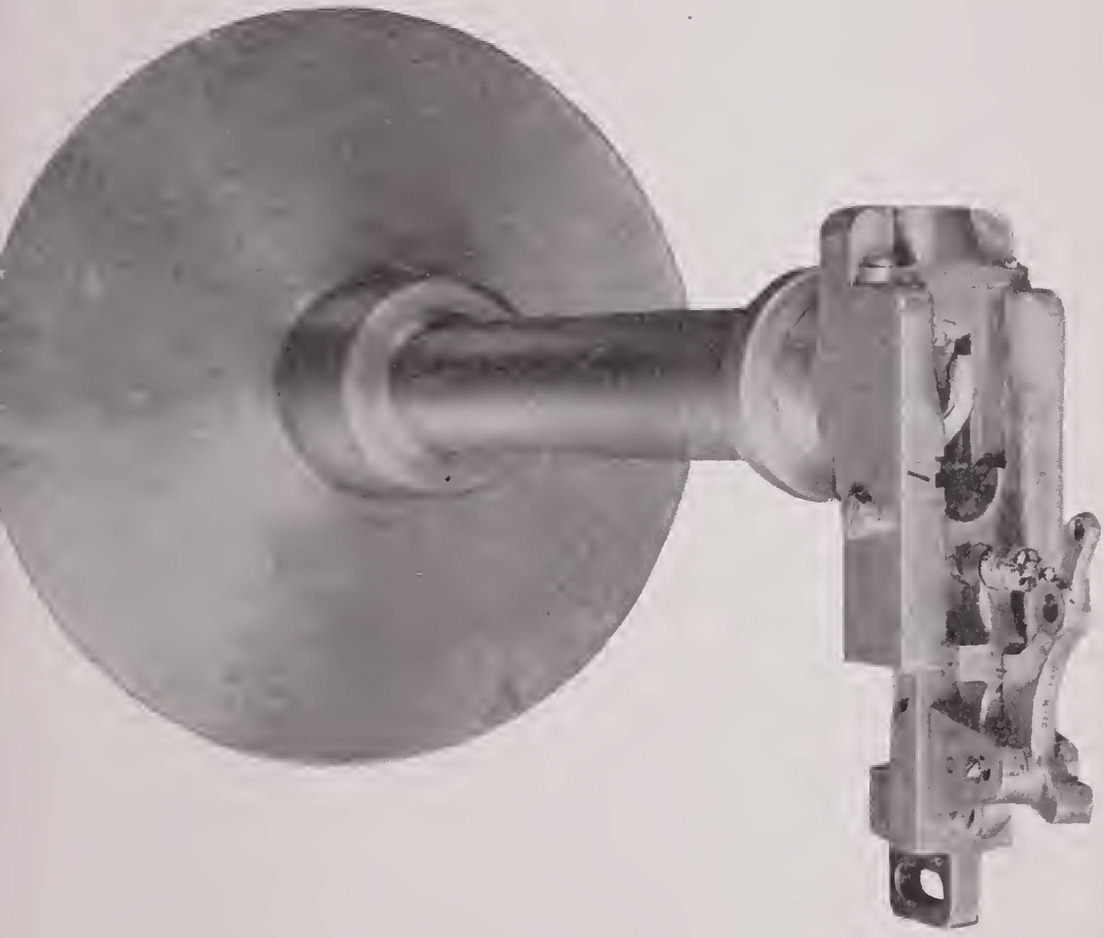
An electric firing mechanism is one in which an insulated firing pin, suitably connected to a firing battery, or other source of electricity, transmits an electric current to the primer and heats a fine wire or bridge therein to a sufficiently high temperature to explode the charge of the primer.

Generally speaking, for the *percussion firing mechanism*, the firing pin, surrounded by a spiral spring has a rectilinear axial movement within the plug, the "cocking" being performed either automatically during the opening of the breech mechanism, or, in continuous firing mechanisms, by hand.

The *electric firing mechanism* has an encased insulated firing pin. The electric contact is not made until the breech block is nearly closed.

470. The *firing lock* consists essentially of a receiver (that screws on the rear of the mushroom stem (see Plates III and X)) containing a "wedge" made so that the "primer seat" may be closed or unmasked for priming. The receiver has a suitable "latch" for locking, and "extractor" for ejecting the primer case, a "firing bolt" with spring, a "sear" and spring for holding the firing bolt "cocked," and a "trigger" to release the sear and to which may be secured a "firing lanyard." The wedge contains a "firing pin" and spring for percussion firing. The shank of the former is struck by the firing bolt, when released.

471. Safety is one of the most important functions of a firing mechanism and special care must be given to it in design. In general, the safety features consist of devices which prevent the firing of the gun until the breech is entirely closed; the details vary with each particular mechanism.



A Firing Lock Mounted on End of Mushroom Stem.

472. Definitions of firing attachments.—These are a part neither of the firing mechanism nor of the breech mechanism, but are certain appliances used to put in operation the firing mechanism. The firing lanyard, electric firing battery, wires, terminals, firing key, etc., are attachments.

473. The two terms "firing mechanisms" and "firing attachments" should not be confused.

Description of Firing Lock, Mark XIV Mod. I.

(Plates III, IV, VII and X.)

GENERAL DESCRIPTION.

474. This firing lock, which is the standard equipment for all the latest 5-, 6-, 14-, and 16-inch breech mechanisms, consists of a "receiver," "wedge," "operator bar," "extractor," and "primer-retaining catch." The wedge is actuated by means of a cam attached in the crank shaft of the breech mechanism. This cam withdraws the wedge and ejects the primer as the breech is opened. Priming is accomplished by hand, and in case of misfire, the lock can be reprimed without opening the breech mechanism by rotating the wedge hand operating lever, thus lifting the wedge operating plunger from the cam; the lock operator bar can then be drawn out, carrying with it the wedge. The wedge actuates the extractor and causes the ejection of the primer. After the new primer has been inserted, the lock operator bar is pressed in against its stop; the wedge operating plunger re-enters the cam slot and gun is again ready to be fired. The firing lock is the same for all mechanisms; operator bars of different lengths, however, are necessary for the various breech mechanisms.

475. The receiver, approximately rectangular in shape, is milled out to receive the wedge. It is secured to the breech mechanism by means of a bayonet joint on the end of the mushroom stem and is prevented from rotating, by the operator bar which is fastened to the wedge. The receiver is drilled for the extractor pin and necessary clearances are milled for the extractor. On one side of the receiver is milled a slot into which a lug on the hammer slides, thus preventing the hammer from being pulled back for percussion firing after the wedge has started to retract. In the front face of the receiver on the side with the milled slot is fitted the

hammer guide block. This block is milled so as to align with the slot and allows the hammer to be cocked only when the wedge is fully closed. It also serves to lift the hammer, thus breaking the contact with the firing pin and preventing electric firing except when the wedge is fully closed.

476. The wedge slides in the receiver and is operated by means of the operator bar. It is prevented from being withdrawn entirely from the receiver by means of a wedge-stop screw passing through the side of the receiver and fitting into a recess milled in the side of the wedge. The firing pin is mounted in insulating bushings at the inner end of the wedge. A hardened face plate is placed in the wedge next to the mushroom stem to take the thrust of the primer when fired. This wedge face plate has a striking lug for actuating the extractor as the wedge is retracted. The inner end of the wedge has a 45° sloping cut to permit of pushing the extractor home, and a circular tapered cut to seat the primer. The wedge is drilled for the hammer thrust pin and the firing spring. The thrust pin, when the hammer is drawn back, protrudes through the wedge into a hole drilled in the cross-head bearing of the breech mechanism. This hole is in alignment with the thrust pin only when the breech plug is fully closed. The thrust pin, due to the action of the firing spring, keeps the hammer in contact with the firing pin except when the wedge is retracted. The wedge is secured to the lock operator bar by the operator bar pin passing through a hole machined in the outer end of the wedge. This hole is elongated to provide for any movement of the mushroom stem to the rear at the time of firing.

477. The hammer has fitted into its right-hand side a spring catch which acts in conjunction with the cocking lever. This catch engages with the latch as the cocking lever is pulled back by the lanyard for percussion firing until their relative positions are such that the hammer is released. When the lanyard pull is released, the cocking lever spring throws the lever forward into its original position and the latch snaps over the hammer catch. The contact piece is housed in an insulating housing in the forward end of the hammer. The lower end rests upon the firing pin when the lock is closed; the upper end carries a terminal to which one side of the electrical firing circuit is connected.

478. **The cocking lever** turns on the cocking-lever axle, directly above and in the same vertical plane as the axis of the hammer. Incorporated with the cocking-lever bearing is a cocking-lever spring which has a torsional action tending to throw the cocking lever towards the lock. One end of the spring engages a recess in its housing in the cocking lever, the other engages a hole in the torsional washer that serves as cover to the spring housing and also as a bearing for the cocking lever. Adjusting of the spring tension is effected by turning the torsional washer in the direction of the arrow stamped on it until the zero mark is aligned with the index line on the wedge. A lug on the right-hand side of the cocking lever extends toward the face of the wedge and serves as a latch to engage the hammer catch when the hammer is to be pulled back for percussion firing. When the cocking lever is in its normal position, the under edge of the latch lug rests on the face of the wedge and transmits to the wedge, instead of through the hammer and to the primer, any accidental blow upon the cocking lever. This precludes accidental firing which might occur were the cocking lever struck when the lock is closed. The hammer, mounted between the wedge and the cocking lever, is amply protected from exterior blows. The slightest withdrawing of the wedge from the closed position removes the firing pin from the percussion cap of the primer and precludes firing electrically or percussively. The outer end of the wedge is so designed that it may be used in connection with the lock operator bars of any of the standard breech mechanisms. Lanyards are secured to the cocking lever by means of a hook. In addition to lanyard firing, the lock may be fired percussively in connection with hand- or foot-operated firing mechanisms incorporated with the various mounts by means of an extension which may be attached to the outer end of the cocking lever.

479. **The extractor** is pivoted in the receiver and fits between the forward face of the wedge and the rear face of the mushroom stem. The extractor arms engage the primer shell on two sides, a clearance cut being provided in the extractor for the primer seat extension on the rear end of the mushroom. The extension is added to the end of the mushroom stem to give better support to the primer. The extractor is actuated by an *extractor cam* which turns on the same pin as the extractor. When the wedge is

retracted the lug on the wedge-face plate strikes the extractor cam, which, in turn, causes the extractor to swing to the rear, lifting the primer retaining catch out of the way and ejecting the primer. This extractor cam is also provided with a torsional extractor spring which returns it to the original position as soon as the wedge is sufficiently withdrawn. In priming, the primer is inserted between the arms of the extractor into primer seat. The head of the primer, seating in a recess cut in rear face of the extractor, pushes the extractor forward until the primer retaining catch engages the primer. The extractor and primer are pushed entirely home by the tapered cut on the inner end of the wedge.

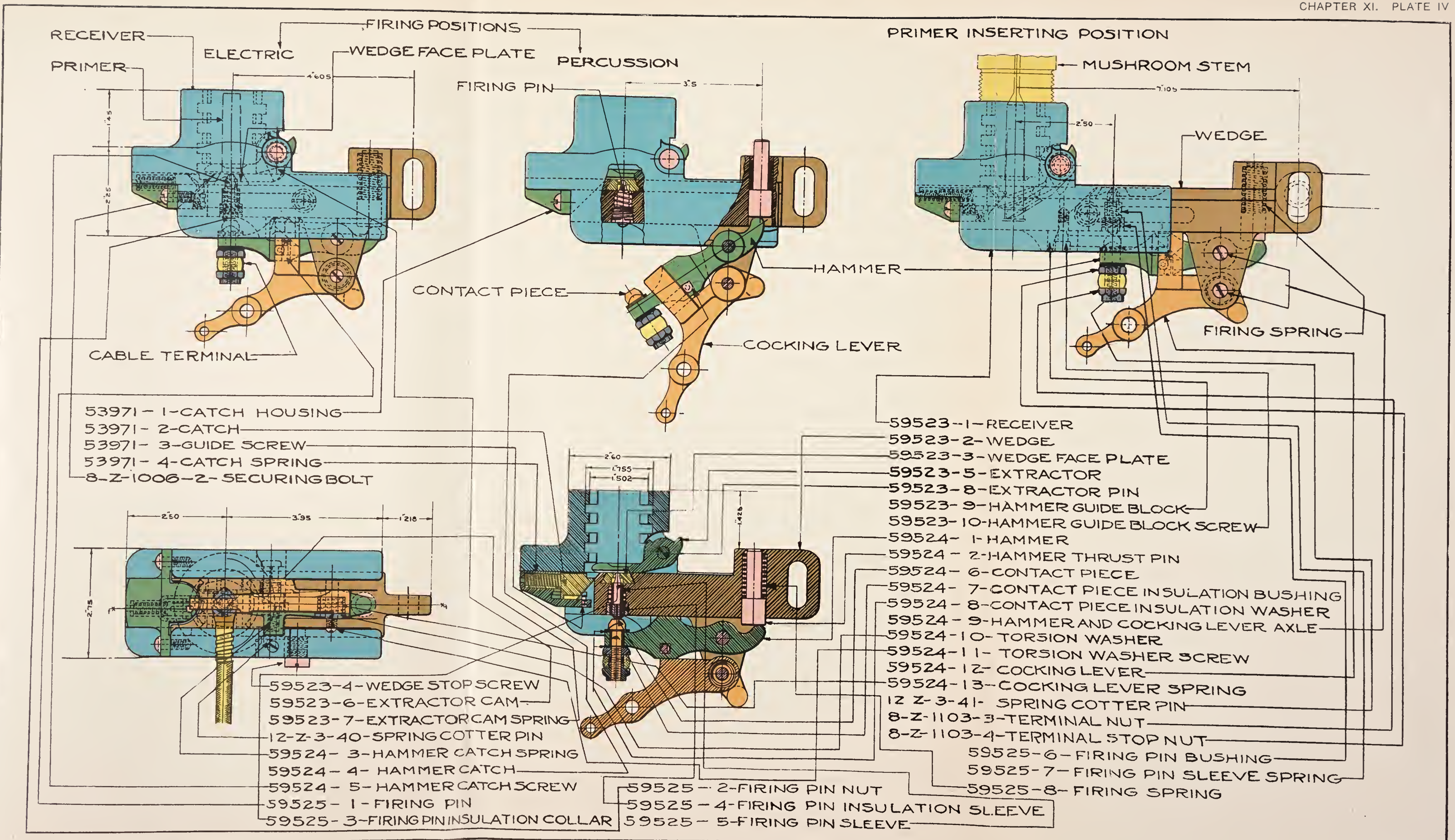
480. The primer-retaining catch consists of a catch housing which is secured to the upper end of the receiver by two screws, a catch which slides in and out of the housing, a guide screw which controls the outward movement of the catch, and a catch spring which keeps the catch in the correct retaining position. This catch sits in rear of the primer seat, and when the primer is inserted in the seat the catch is pushed in until the head of the primer is engaged by the forward face of the catch. When the wedge is closed and the primer is pushed home, the end of the wedge pushes the catch into its housing. When the primer is ejected, the arms of the extractor force the catch out of the way of primer.

481. The lock-operator bar is secured to the carrier by means of a T-slot. The movement of the bar is controlled by a wedge operating plunger. The stop plunger is housed in the operating bar, being held in the housing by means of a stop plunger key fitted in the forward face of the operator bar, a stop plunger spring being used to keep the plunger against the key. A stop plunger pull ring is attached to the end of plunger to enable the plunger to be lifted over the cam surface when withdrawing the bar from the carrier. This plunger works against a machined surface in the carrier and only allows the bar to be moved the distance necessary to close the wedge and to align the firing pin with the primer.

482. The wedge-operating plunger is housed in the outer end of the operator bar, the end of the plunger entering the slot in the operating cam. This cam being secured to the operating handle of the breech mechanism causes the lock to open and close with the opening and closing of the breech mechanism. The wedge operating plunger is secured in the housing by means of a wedge

operating plunger pin and plunger pin detent and is kept in the cam slot by means of a wedge operating plunger spring. Over the housing for the wedge operating plunger is secured the wedge hand operating lever. This lever has two helical slots diametrically opposite, through which it is secured to the housing by a plunger pin and by which, when the lever is pushed outward, the wedge operating plunger is lifted out of the cam slot. The operator bar can then be moved outward, withdrawing wedge. The wedge hand operating lever is used only for repriming or in assembling or disassembling the lock. The inner end of the operator bar is secured to the wedge by means of an operator bar pin with a spring detent.

483. Safety appliances.—The primer cannot be fired either electrically or by percussion until the breech mechanism is completely closed. The surface of the cam on the outer side of the cam slot is cut down to allow the wedge operating plunger to move over it in withdrawing the operator bar from the side. The surface of the cam on the inner side of the slide is too high for the plunger to slide over it, and as this surface follows the slot it prevents the operator bar (and wedge when fastened to the bar) from being closed until the breech mechanism is closed. A lug on the hammer engaging in a recess mill in the receiver lifts the hammer so as to break contact and prevent electric firing. This same lug also prevents the hammer from being drawn back for percussion firing, except when the wedge is fully closed. A pin is screwed into the carrier, fitting against the receiver, to prevent the lock from being turned in the wrong direction when disassembling or when disengaged from the operator bar. An arc plate is secured to face of carrier to preclude the possibility of the lock being turned until the wedge is retracted. It also prevents the wedge from being closed until the lock is in its proper position. If the pin locking the operator bar to the wedge is disengaged, by any means whatsoever, the arc plate on the carrier automatically withdraws the wedge from firing position, thus preventing jamming and putting the wedge in the safe position so that the gun cannot be fired. When the receiver is in its correct position, with the wedge disengaged from the operator bar, and the breech mechanism is open, the wedge is prevented from being closed by a shoulder on the end of the cross-head bearing of the breech mechanism which will then be in front of the shoulder on the wedge.



FIRING LOCK, MARK XIV, MOD. I, NOMENCLATURE SHEET.

3-Inch Semi-Automatic Breech Mechanism, Mark V.

(Plate V.)

484. This mechanism, and the 3-inch Mark IX, are the only 3-inch semi-automatic breech mechanisms used on U. S. Naval guns that are now in service. Both mechanisms are similar and are of the vertical sliding wedge type, which have been sometimes designated as the "Driggs-Seabury semi-automatic mechanisms." Several modifications have been made to remedy minor defects in the original design.

485. The semi-automatic operation is as follows:

When the gun recoils the tumbler crank on the left end of the crank shaft, *H* (Fig. 2) passes over the thrust cam, *B* (Fig. 8) forcing the latter down to the rear through 68° to 74°. After the tumbler crank has passed by the thrust cam, the thrust cam is released and returned to its original position by the thrust-cam spring (Fig. 5) so that on counter-recoil the tumbler lug brings up against the thrust cam (Fig. 9) and forces the crank shaft to rotate, thus causing the block to drop. As the crank shaft is rotated the operating spring (Fig. 1) is compressed by means of the operating-spring piston and operating-chain stud on the right end of the crank shaft. As the block descends, the extractor lug *C* (Fig. 5) follows the extractor groove in the block, forcing the lower end of the extractor forward and the upper end to the rear, accomplishing extraction. The extractors are held to the rear while the breech is open by means of the extractor springs *D* (Fig. 4) and plungers, one to each extractor. These springs prevent the extractors from jarring forward upon the return of the gun to battery and causing premature closing of the breech. The block is held down by the inner lugs of the extractors, bearing on shoulders (*M*, Fig. 4) in the block at the top of the extractor grooves. When the cartridge is loaded and brings up against the extractor nibs, the latter are forced forward and the extractor lugs aft, the extractor lugs becoming disengaged from the shoulders on the block. The block is closed by means of the operating spring contained in a sleeve fitted on the right side of the gun. This spring is compressed on counter-recoil and remains in compression until the gun is again loaded. When a cartridge is loaded the extractor releases the plug and the operating spring closes the breech.

486. The cocking is accomplished as follows (see Fig. 4):

As the block rises the cocking lever toe *E* brings up against the sear nib, drawing back the firing pin and compressing the firing spring. The sear *F* fits into the left of the breech housing and is held in position by means of the sear spring plunger and sear spring *T* fitting into the left and rear of the breech. The sear is operated by the trigger bar which is operated by the trigger pull, acting through the trigger lever, trigger bar, head, and adjusting nut. When the trigger is pulled the sear is rotated against the force of the sear spring, the cocking lever is released by the sear nib and the firing pin flies forward. If the trigger were lashed back and the trigger bar in suitable adjustment, firing would result automatically as soon as the breech closes.

487. The semi-automatic feature can be eliminated by turning the thrust cam *B* (Fig. 7) to the rear and down, thus permitting the tumbler crank on the crank shaft to pass above the cam as the gun returns to battery. For this purpose there is a tumbler latch *K* (Fig. 5) fitted in the tumbler cover which holds the thrust cam down and to the rear. The crank shaft rests in a cradle projection under the gun and is held in place by means of a lock plate *L* (Figs. 4 and 5) fitted to the bottom of the breech housing by means of two dove tails and secured by means of the lock-plate pin. As the crank shaft is rotatèd the studded end of the breech-block crank moves along a sloping cam surface on the under side of the block, raising or lowering it. The tumbler crank on the left side of the gun opens the breech on counter-recoil as previously explained.

488. Operating lever clutch mechanism (Fig. 3).

This mechanism is for the purpose of preventing rotation of the operating lever when the gun works semi-automatically.

Where the operating lever is hollowed out to receive the end of the crank shaft, there is left a projecting sector of metal about ½ inch thick. When the breech is closed and the operating lever is upright, the upper vertical face of this sector is against the corresponding face of the sector on the end of the crank shaft (Fig. 2). Consequently, rotation of the operating lever, when the breech is closed, will rotate the shaft, but rotation of the shaft will not rotate the lever since the shaft sector will move in a blank space.

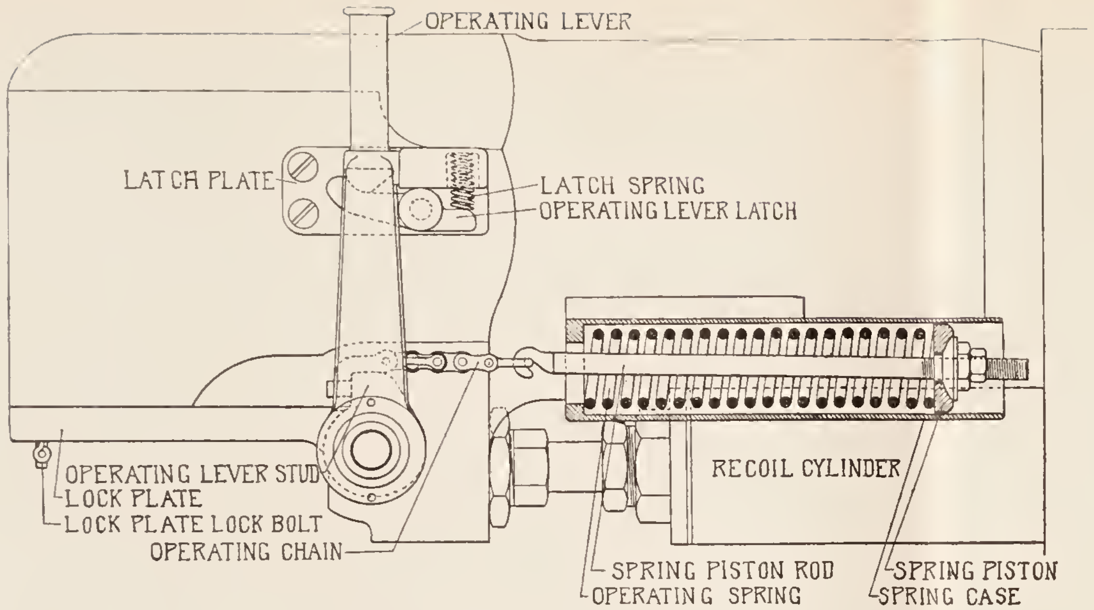


Fig. 1.—Right Side of Gun. (Breech closed.)

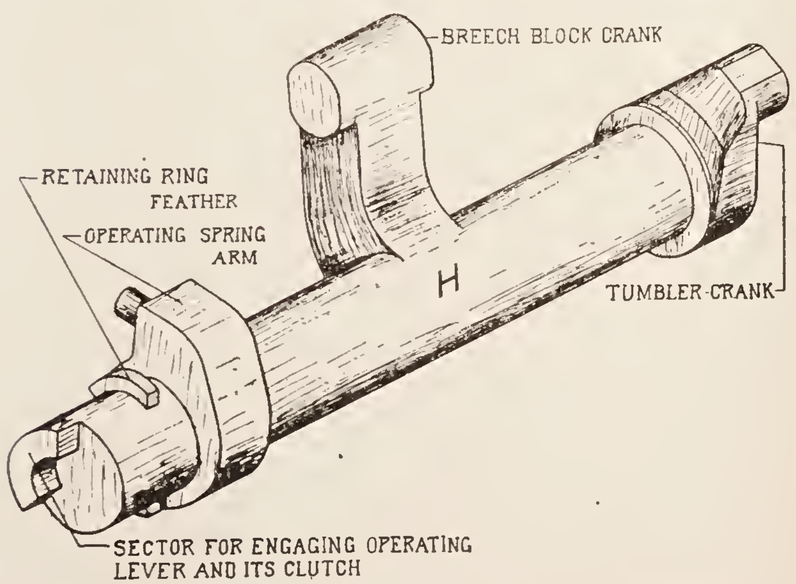


Fig. 2.—Crank-Shaft.

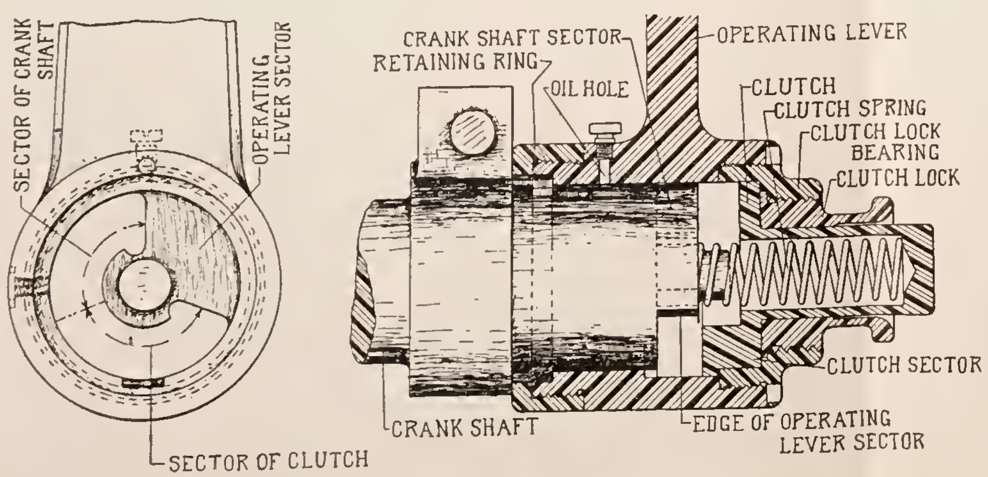


Fig. 3.—Clutch-Mechanism.

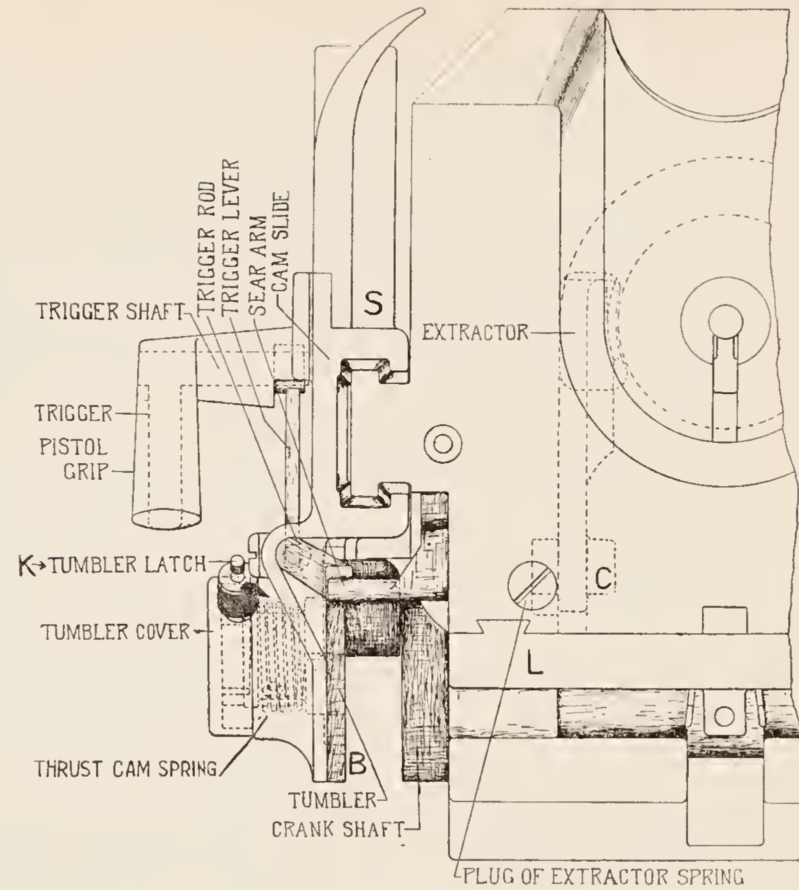


Fig. 5.—Rear View. (Breech closed.)

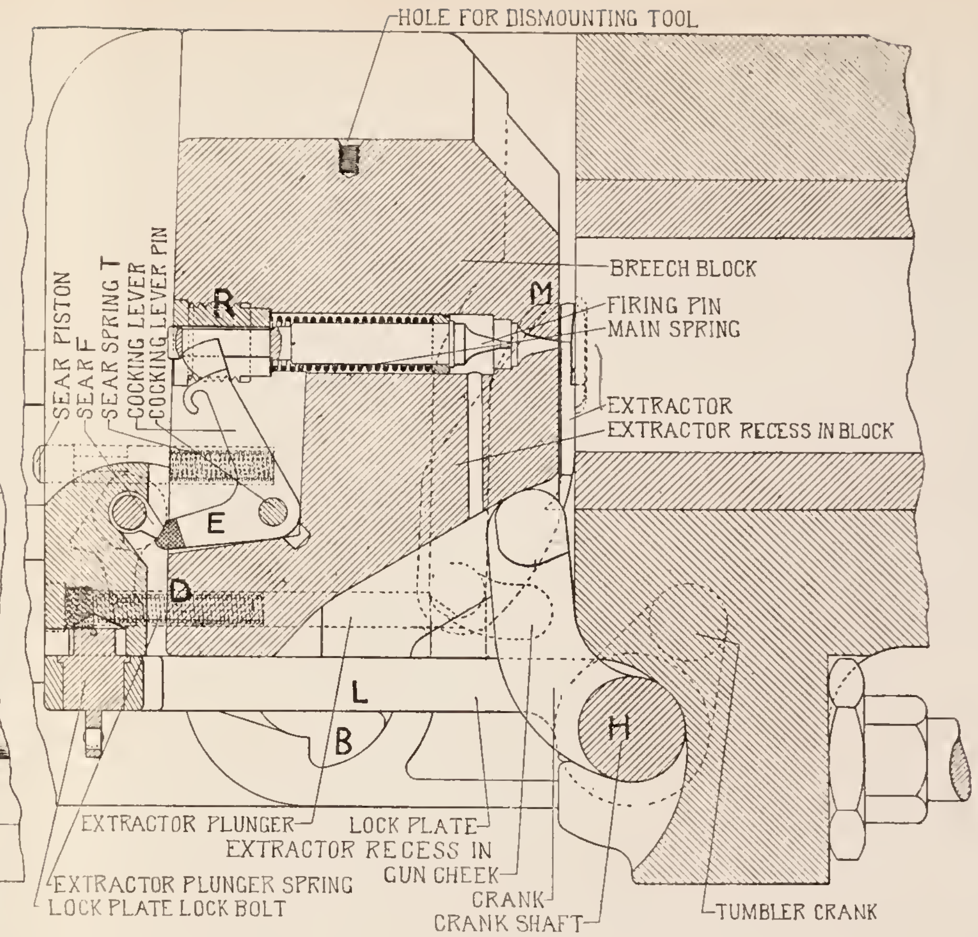


Fig. 4.—Gun Closed. (Breech closed.)

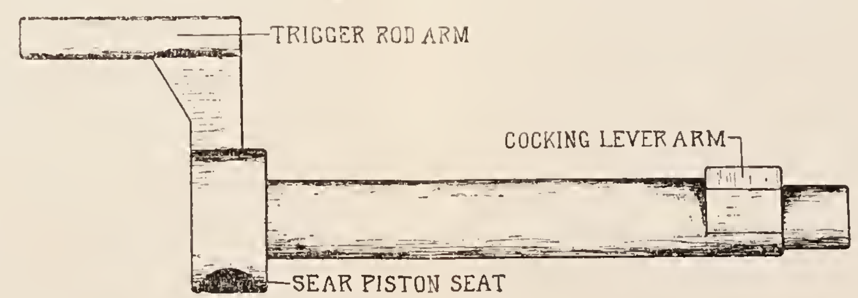


Fig. 6.—Sear.

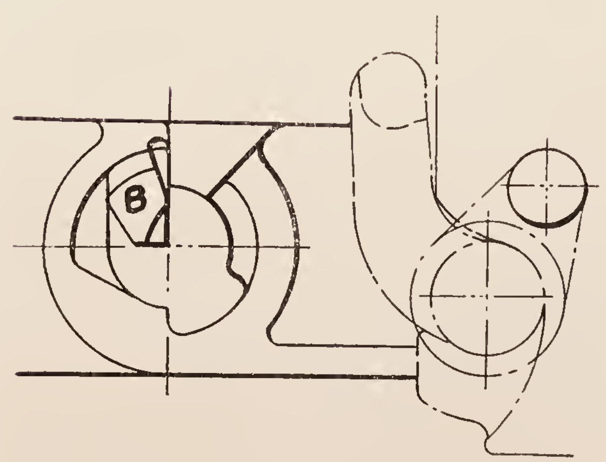


Fig. 7.

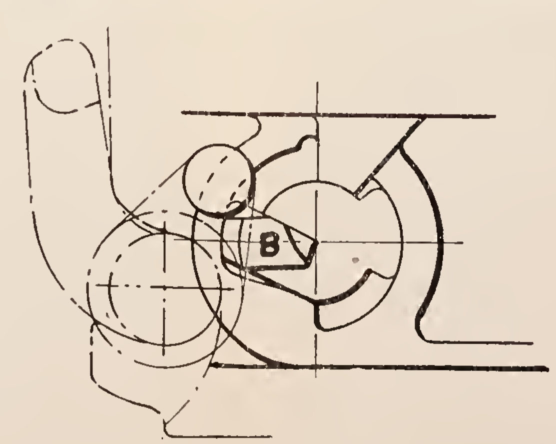


Fig. 8.

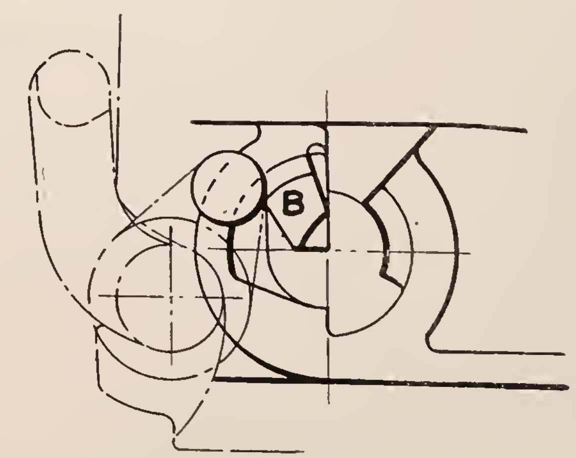


Fig. 9.

3-INCH S.-A. MECHANISM, MARK V.

By screwing in the clutch lock, the clutch is carried to the left against its spring and the sector on the left end of the clutch lock fills the space between the two other sectors, thus locking the shaft and operating lever together. When the gun is to function semi-automatically, the clutch lock should be screwed all the way out.

5-Inch Breech Mechanism, Mark VII.
(Plates VI. and VII.)

489. Introductory.—The description in detail of the 5-inch Mark VII breech mechanism follows: Except for minor details. this description covers also the 6-inch Mark X, 8-inch Mark VI, 12-inch Mark IX, and 14-inch Marks II, III, and IV breech mechanisms.

In designing a carrier mechanism for turret guns, one of the most important difficulties to be overcome is to avoid slamming of the plug, which, due to its greater weight as compared with medium caliber mechanism, would necessarily bring severe strains upon the carrier and the operating mechanism. It is also desirable to avoid the use of gearing as much as possible, to reduce the number of parts and to transmit the power by means which reduce the friction to a minimum.

In fitting the firing mechanism, it is necessary, for safety, to prevent priming until the plug is locked, and to provide for easy repriming without danger to the personnel in the case of misfire.

For overcoming the ill effects of the slamming of the plug as it swings into the screw box, it is possible to change the motion of translation of the plug into one rotation, thus cushioning the blow and utilizing the swinging energy of the plug to assist in locking it. This is done by means of a cam slot in the breech, and a follower pin on the plug. To avoid the use of gears, and still obtain the necessary power for unlocking, a crank shaft, with lever attached, is the most efficient device. To avoid the complication necessary to obtain a continuous motion of the operating lever to both rotate and swing the plug, it is found that the cam action which changes the swinging motion into rotating motion of the plug also changes the direction of motion of the operating lever and permits of quick and easy operation of the plug, with the lever arranged to swing in two planes instead of one. This movement of the lever in a vertical plane around the

crank shaft for rotating the plug, and in a horizontal plane around the hinge pin for swinging it, results in several desirable features being obtained, as follows:

1. It eliminates the use of a carrier latch or a plug latch.

2. The operator stands entirely clear of the recoil.

3. When the plug is closed, the lever is in such position as to allow the plug man to catch it as the gun returns to battery and, by holding on to it, to have the forward movement of the gun unlock the mechanism.

4. It permits of a design of mechanism which does not require right or left hand parts.

The speed of the mechanism depends entirely upon the dexterity of the operator, but it has been found that the plug can be opened or closed by an unskilled operator in two seconds with the gun level. Any greater speed is not recommended. It has also been found possible for one man to close the plug with the gun-elevated to an angle of 8°. With one man on the operating lever and one man pushing on the plug, it has been found practicable to close the mechanism at any angle of elevation.

The introduction of the rotating-cam slot and follower pin uses the energy stored up in the moving mass either to rotate the plug when closing or to swing out the mechanism when opening, and eliminates slamming and rebounding of the plug. It does away with the necessity of a closing buffer and the customary tray or carrier latch.

Inefficient forms of power transmission, such as gears, racks and worms, have been eliminated, and bearings with large surfaces have been introduced instead. A ball bearing on the upper hinge lug carries the dead weight of all swinging parts.

The number of pieces has been greatly reduced.

490. General design.—This breech mechanism is designed to fit the 5-inch powder bag gun. The breech mechanism is of the carrier type, with the Welin breech plug, De Bange gas check system and a new type of operating mechanism and firing mechanism.

491. The carrier (see Plates VI and VII and Fig. 74) is journaled on a vertical hinge pin on the right hand side of the gun. The carrier extends across the breech face of the gun and has a projecting hub on which the breech plug is journaled. The operat-

ing lever is attached to a shaft journaled in the carrier. The other end of this shaft carries an overhung crank, the pin of which engages a cross-head which works in a cross-head bearing set into the rear face of the breech plug.

492. To open the mechanism, the operating lever is swung to the rear in a vertical plane. This rotates the crank shaft, which, by means of the cross-head, rotates and unlocks the plug. The operating lever is then swung to the side in a horizontal plane, which swings the carrier and plug clear of the breech. Reverse motions close the breech. A salvo-latch locks the operating lever in position so that it can only be unlocked by the recoil of the gun or by hand.

493. Screw-box liner and breech plug.—The rear end of the gun jacket is threaded to receive the screw-box liner. The gas-ejector valve (not shown) is secured to the rear flange of the screw-box liner, and is opened when the breech plug is started to the rear in opening the breech. Air from the valve passes to two channels turned on the outside of the screw-box liner, and from these through ducts to the inner side of the screw-box liner and to the bore of the gun.

The screw-box liner and the breech plug are slotted to form 12 sections—4 blanks, and 8 threaded steps in four groups, the blanks being wider than the threaded steps to permit the action of the rotating cam.

The breech plug is of the Welin or stepped-screw type, having abutment threads with the pressure side the steeper. The center of the plug is bored out to provide a bearing for the mushroom stem and to receive the threaded hub of the carrier. This thread has the same pitch as the external thread on the plug.

494. Mushroom and gas check.—The gas check system is of the De Bange type, consisting of a mushroom, gas-check pad, and gas-check rings (see Fig. 67).

The stem of the mushroom extends to the rear through the breech plug and the hub on the carrier. The mushroom can move longitudinally, but is prevented from rotating by a key attached to the carrier. A helical spring located in a recess in the carrier and encircling the mushroom stem butts up against a nut on the same, and thus holds the mushroom in place. In rear of the nut, the mushroom stem has a bayonet joint for attaching the firing-lock

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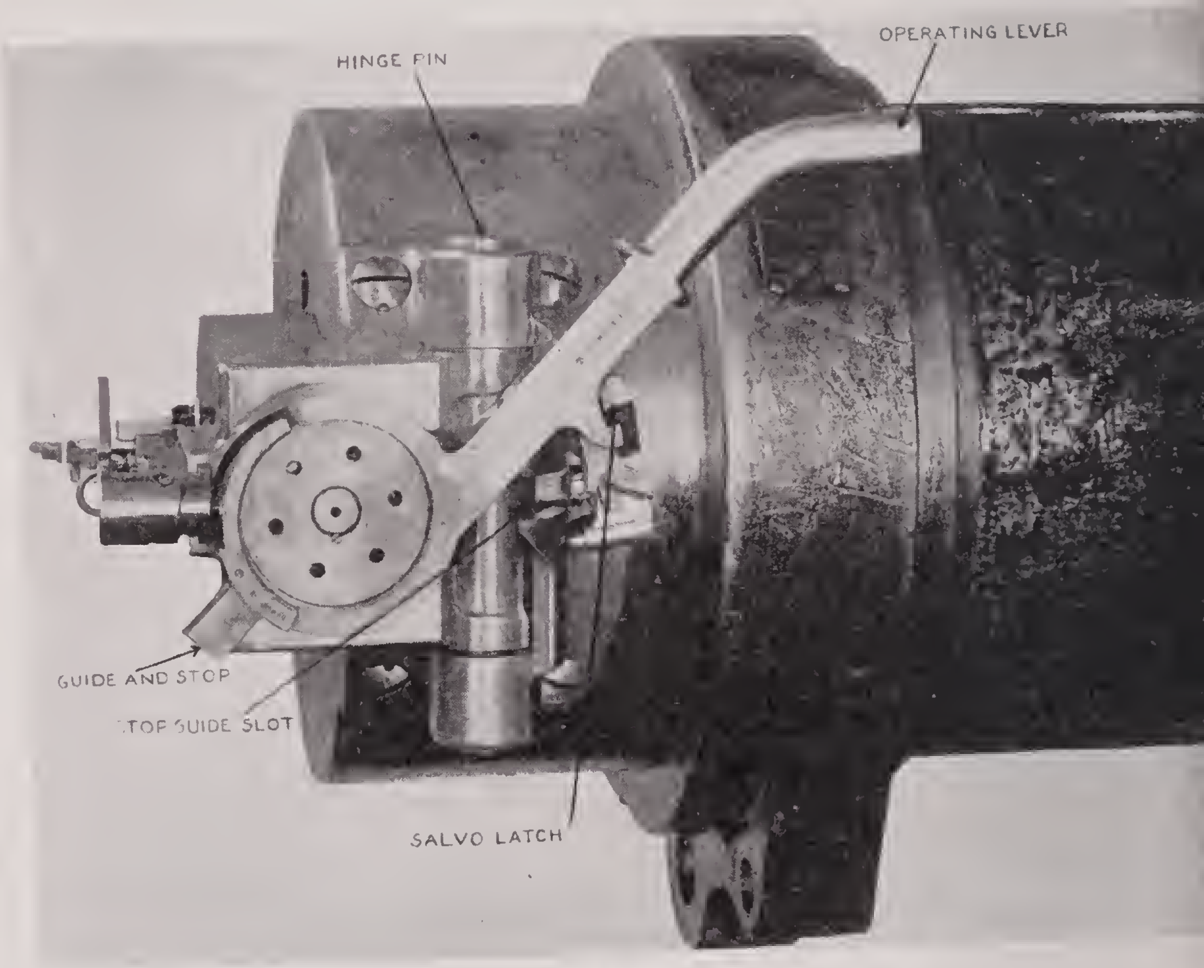
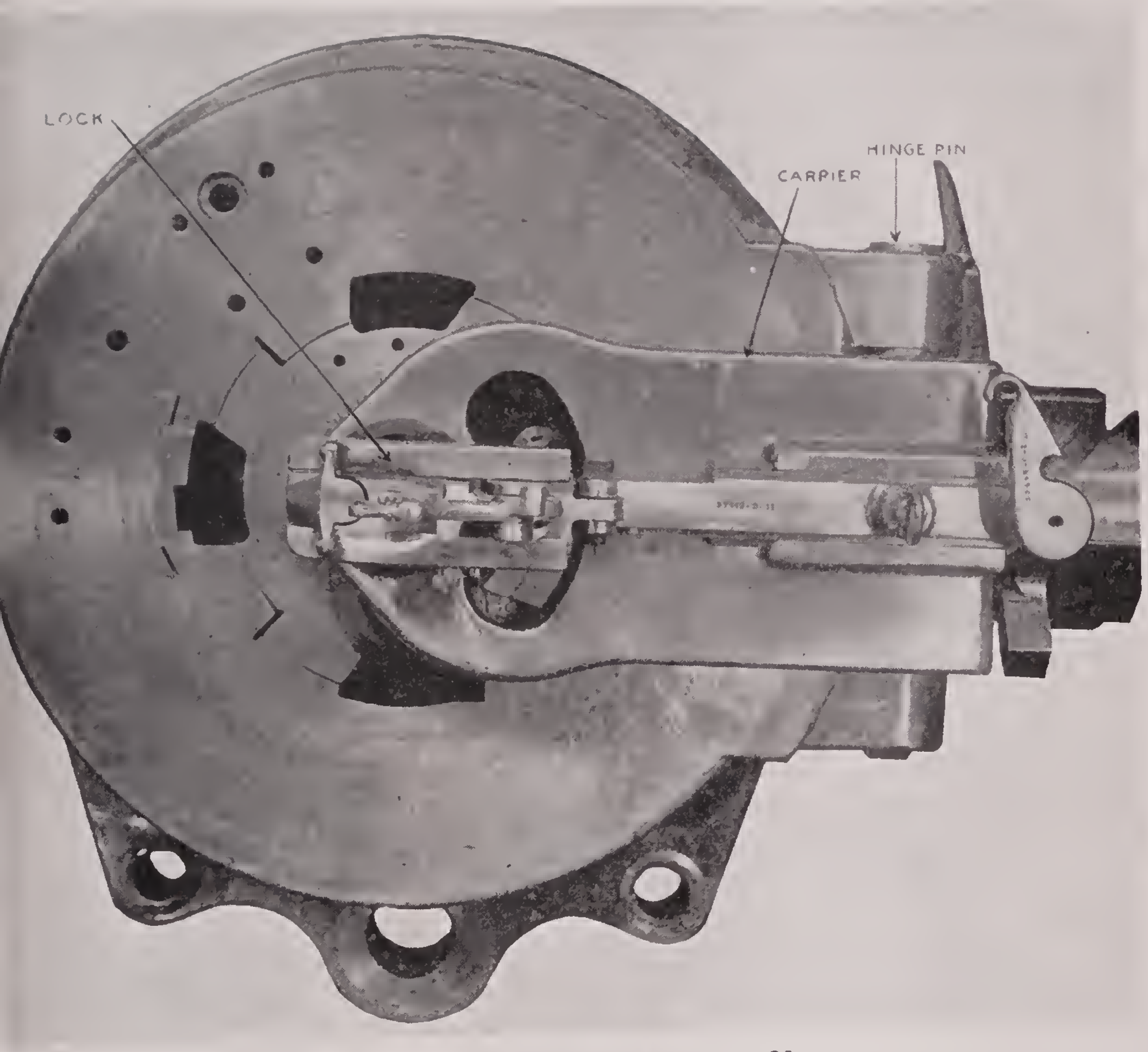


5-Inch Breech Mechanism—Side View.



5-Inch Breech Mechanism—Rear View.

receiver. The vent extends from the face of the mushroom through the stem, the end of which is bored out for the primer seat.

495. Operating mechanism (Fig. 74).—The crankshaft. which extends through the carrier, is provided with two bearings. The inboard bearing engages the portion of the crank shaft adjacent to the overhung crank.

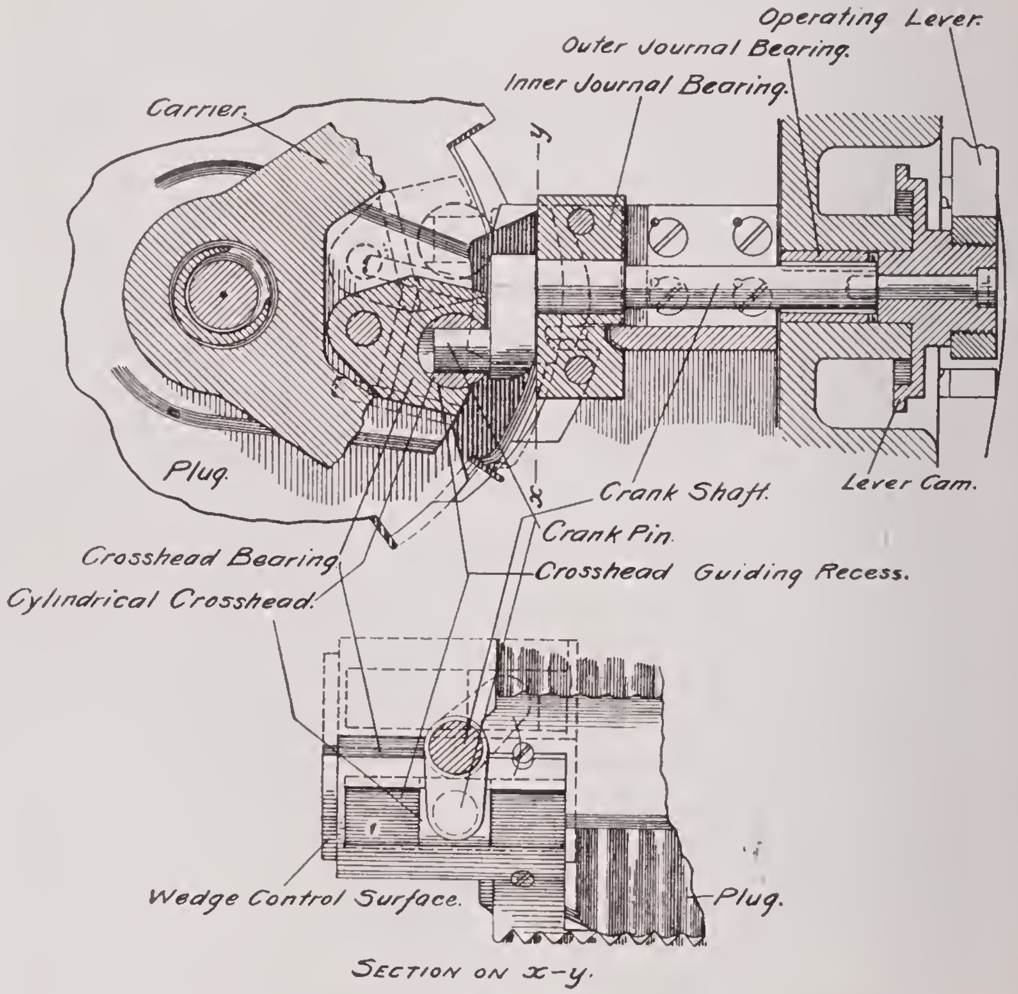


FIG. 74.—OPERATING-MECHANISM FOR 5-INCH BREECH-MECHANISM, MARK VII.

The outboard bearing for the crank shaft is machined in the shoulder of the carrier casting, which is bored out to fit a steel sleeve keyed to the crank shaft. To this sleeve is attached the operating lever and firing mechanism cam, these parts being keyed to the outer portion of the sleeve and clamped in position against a collar on the sleeve by the circular flange of a nut threaded on the extremity of the crank shaft and seated in a counterbore in the end of the cam.

In the rear face of the plug, and located near the right hand edge, at an angular distance above the horizontal center line (unlocked) position equal to half the angle of rotation is a counterbore into which is rigidly fitted a hollow, cylindrical cross-head bearing. The cross-head, which is housed in the cross-head bearing, engages the crank pin of the overhung crank, the parts being so arranged that the cross-head is capable of both a rotary and a sliding motion with respect to its bearing and crank pin.

When the plug is closed and locked, as during firing, the operating lever extends upward and toward the muzzle, making an angle of 43° with the vertical. The cross-head and bearing are below the horizontal center line at an angular distance of 16° 42′ 30″ (equal to half the rotation of the plug) and the crank shaft is in the dead center position, with the crank pin directly in line with the center of the shaft when viewed in the plane of rotation of the plug. The plug is thus securely locked against any rotary tendency produced by reason of the chamber pressure and the inclination of the plug threads.

496. To open the breech, the operating lever is moved to the rear until it reaches the horizontal position, turning the crank shaft through an angle of 133°. The corresponding circular motion of the crank pin is resolved by the cross-head within its bearings and an upward movement of this bearing, which, being rigidly attached to the plug, causes a rotation of this member in the direction required to disengage the threaded steps. At the beginning of this motion, as the crank pin leaves the dead center position a large angular movement of the lever and crank shaft will produce but a small rotation of the plug, with a corresponding increase in the force available to unseat the gas-check pad.

497. Plug-rotating cam.—The total angular movement of the plug produced by the rotation of the crank shaft is 33° 25′, of which movement but 26° 42′ 5″ is required to disengage the threads, the remainder of the rotation occurring as the carrier begins to swing away from the gun, thus affording an easy transition from the rotary motion of unlocking the plug to the translatory motion of swinging it out of the breech. This effect is accomplished by the plug-rotating cam, which is fitted in a dovetail in the blank between the threaded sections on the left side of the screw box, and consists of a hardened-steel plate into which is cut

a curved cam-slot coinciding in its forward portion with the pitch of the screw-box threads, and running out at the breech face in the path of the parts swinging about the hinge pin. This cam slot engages a stud or cam follower projecting from the side of the breech plug, and guides it during the latter part of the motion of unlocking, so that, as soon as the threads of the plug are disengaged, the rear-ward motion of the plug and carrier, in swinging about the hinge pin, is gradually started without the shock to the mechanism or to the operator which would result were the direction of motion changed suddenly. The advantages derived from the use of the plug-rotating cam are most marked during the act of closing the breech, when, by checking gradually the velocity of the swinging parts, it serves to avoid the objectionable slamming and rebounding of the carrier by utilizing and absorbing the energy of the swinging parts in imparting a rotary motion to the plug and operating lever.

498. Operating-lever guide and stop (see Plate VI).—The rearward swing of the carrier about the hinge pin, commenced by the plug-rotating cam, is continued by the operating lever until the mechanism has been swung through 90°, when further swing is limited by recessed stops on either side of the carrier hinge, which come up against corresponding abutments formed upon the hinge lug forging. While the mechanism is open, the plug is prevented from rotating and is maintained in the unlocked position by the operating lever guide, a projection from the hub of the operating lever, which, as the outward movement of the mechanism about the hinge pin commences, enters a guide slot in the hinge-lug forging. This device and the rotating cam prevent the plug from rotating while the threads of the plug and screw box are disengaged.

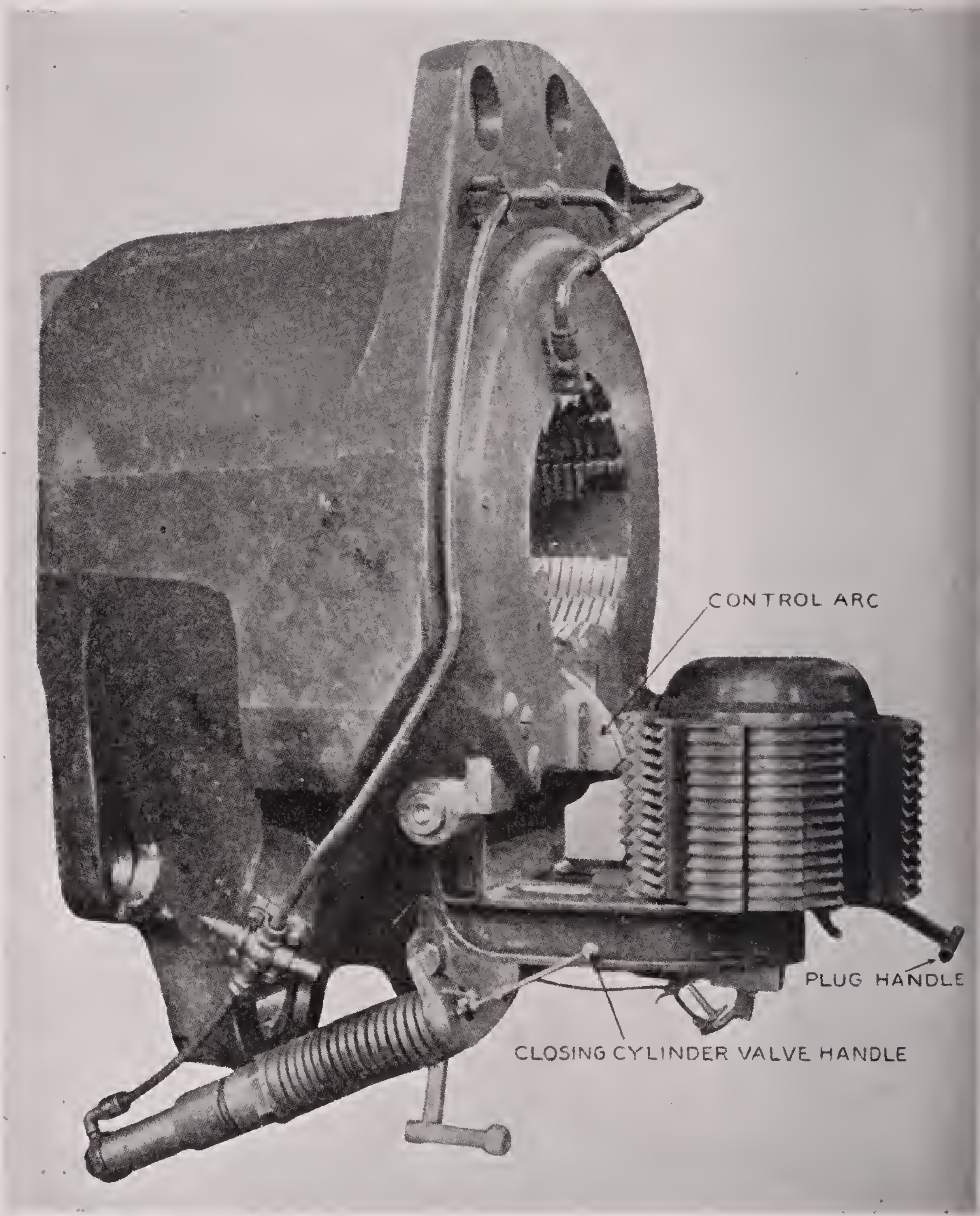
To guard against the failure of the guide on the operating lever hub to enter fairly the guide slot, which might occur if lost motion should develop in the operating gear, an operating lever stop is provided to limit the rotation of the lever and crank shaft. This stop consists of a pin driven through the hub of the operating lever, and which is provided with a stud projecting inwardly to engage a slot milled in the outboard end of the carrier (not shown).

499. Operating-lever latch (salvo latch) (Plate VI).—The lever latch consists of a latch member journaled on a screw bolt attached to the forward edge of the hinge lug in line with the operating lever guide slot. A locking plunger is mounted in a recess directly in the rear of the latch boss, and in such a position that the plunger is retained in place by an overlapping portion of the latch. The upper portion of the latch is broad and heavy, and is machined at its upper extremity to engage the hook or catch formed on and projecting from the under side of the operating lever. The lower part of the latch is made as light as possible, and is bored out to provided a bearing for the latch-spring and plunger, which, by acting against the hinge lug, throw the latch into proper position to engage the catch on the operating lever.

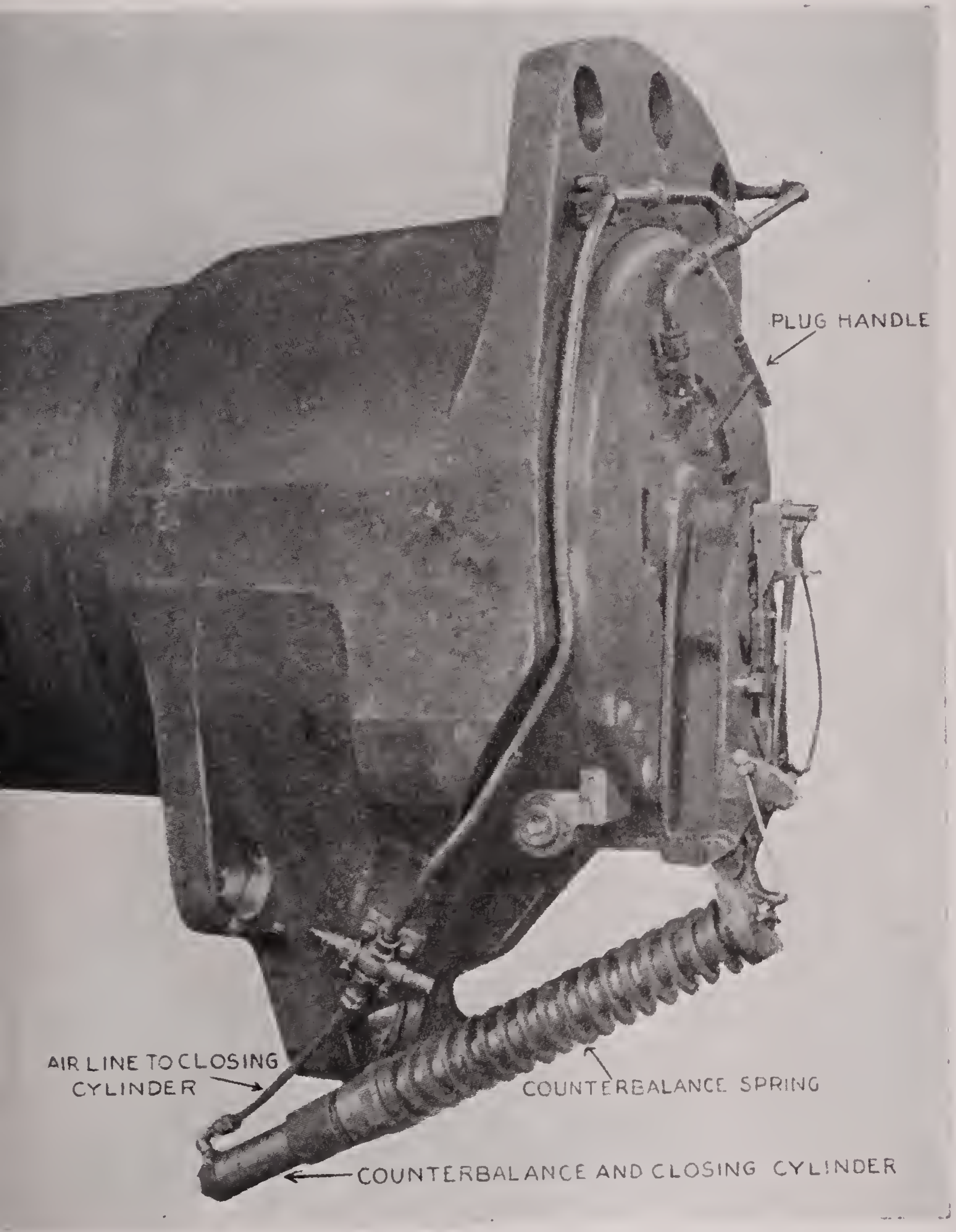
During recoil, the inertia of the upper and heavier parts of the latch causes it to rotate on its pivot so that the lower portion moves to the rear toward the hinge lug, compressing the latch spring, and the upper portion moves forward and out of engagement with the catch on the operating lever. The latch is held in this released position by the locking plunger, which, under the impulse of the locking plunger spring, moves out and engages a notch in the latch as soon as it is brought into line by the rotation of the latch. When the breech is opened the lug on the operating lever strikes the locking plunger, compressing its spring, and moves the projecting stud out of engagement with the notch in the latch, which thereupon, under the action of the latch spring and plunger, is returned to the " set " position ready to engage the catch on the operating lever when the breech is closed. The top part of the latch serves as a stop which comes up against the hinge lug and limits the rotation of the latch.

As the latch does not release automatically except upon the discharge and recoil of the gun, it gives warning of misfires, or hang fires, which might pass unnoticed when a number of guns are being fired in salvo. In such case, the breech can only be opened after releasing the latch by hand.

500. Firing mechanism.—This breech mechanism is fitted with the Mark XIV Mod. I firing lock previously described.



14-Inch Breech Mechanism, Mark III, Modification I.
Plug Open—Side View.



14-INCH BREECH MECHANISM, MARK III, MODIFICATION I.
PLUG CLOSED—SIDE VIEW.

14-Inch Breech Mechanism.

(Plates VIII, IX and X.)

501. **General design.**—The 14-inch Mark III Mod. I breech mechanism is similar to the 5-inch Mark VII (Naval Gun Factory design). The principal features in which this mechanism differs from the breech mechanisms of the same type on other guns are enumerated below.

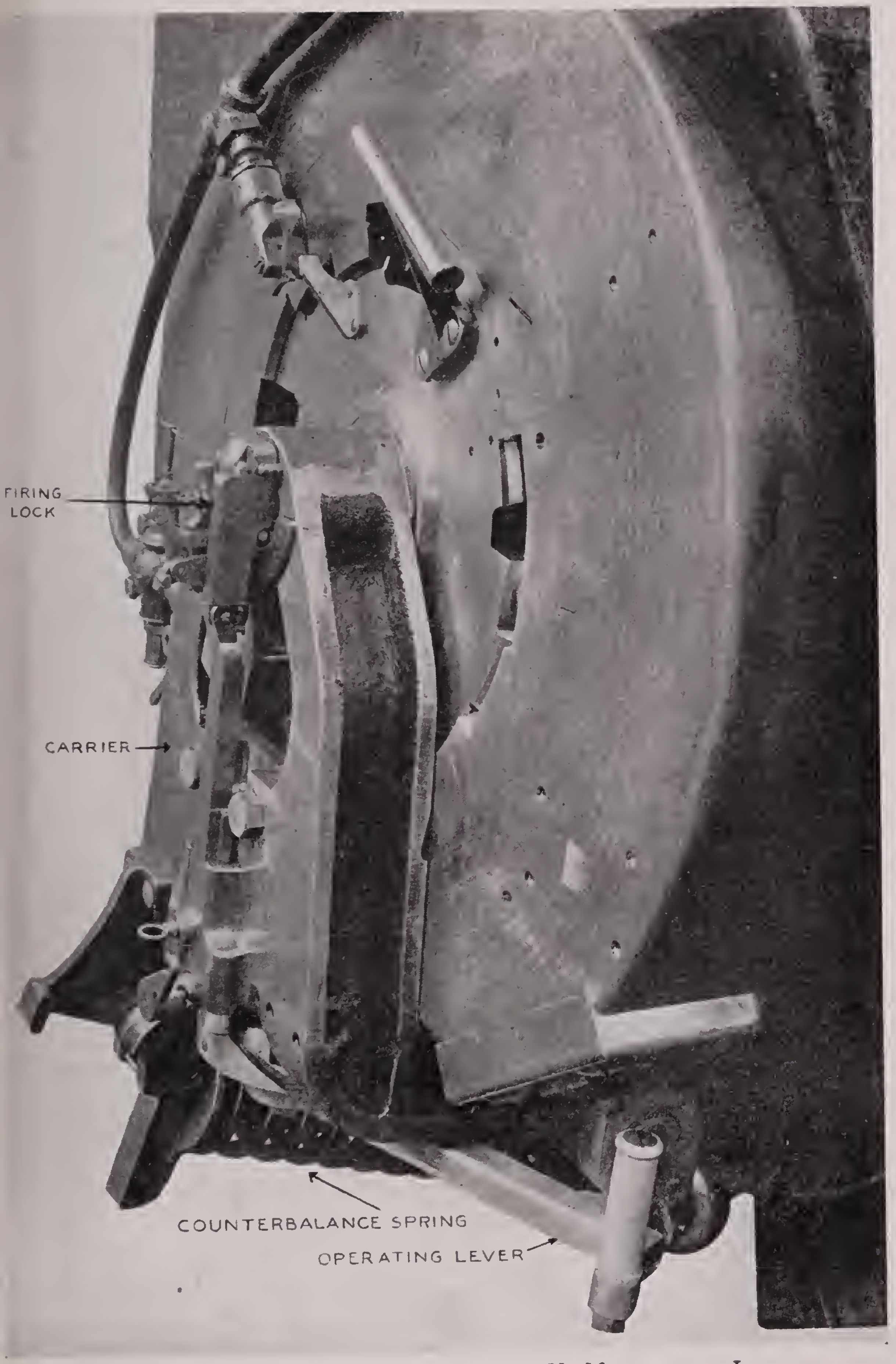
This breech mechanism is adapted to guns mounted in three-gun turrets, by turning it through 90°, so that the carrier opens downward. The operations of opening and closing the breech mechanism are facilitated by the introduction of a counter-balance spring and a closing cylinder operated with compressed air.

The carrier is provided with trunnions which are journaled in hinge lugs, fitted in recesses cut in the front side of the flange on the screw-box liner. The hinge lugs are screwed in place by body-fit bolts. The carrier extends upward across the breech face to the center of the gun, where it has a projecting journal which carries the breech plug. The operating lever is attached to the lower end of a vertical shaft which is journaled in the carrier near the center line. The upper end of this shaft carries an overhung crank, the pin of which engages a cross-head which works in a cross-head bearing, set in the rear face of the breech plug.

502. **To open the mechanism** the operating lever is swung to the rear and left either by hand or by means of a lanyard. This rotates the crank shaft, which, by means of the cross-head, rotates and unlocks the plug. The mechanism is then swung open to the rear and downward by means of the plug handle and its own weight. When open, the mechanism is supported by the counter-balance spring, which also serves as a buffer.

When the valve which admits compressed air to the closing cylinder is opened, the air pressure on the piston closes the mechanism. This air is taken from the gas ejector system, and before reaching the inlet valve passes through a reducing valve which maintains a constant pressure independent of the fluctuations in the air line. The operating lever is locked in the closed position by the salvo latch, and is unlocked by the recoil of the gun or by releasing the salvo latch by hand.

503. **Control arc and stops.**—The rearward swing of the carrier about the hinge pin, commenced by the plug-rotating cam, is continued by means of the plug handle until the mechanism has swung through an angle of 90°, when further swing is limited by



14-Inch Breech Mechanism, Mark IV, Modification I.

the counter balance and a stop. While the mechanism is open the plug is prevented from rotating in the closing direction by the control arc engaging the adjacent high section of the plug (see Plate VIII). The control arc is a circular steel segment, concentric with the hinge, and is bolted to the screw-box liner between the hinge lugs.

504. **The counterbalance and closing cylinder** (Plate IX) is supported by the closing cylinder bracket, which is pivoted in a journal under the recoil cylinder lug of the yoke. The spring-rod piston, which works in the closing cylinder, is extended upward and to the rear by the spring rod. The spring rod terminates in a head with an offset hook which bears on a pin in the carrier cam bracket. The cam bracket is bolted to the left hand hinge pin boss of the carrier. The counter-balance spring surrounds the spring rod, and extends from under the head of the latter to the spring adjusting nut which is screwed on the outside of the closing cylinder. By means of this nut, the tension of the spring is adjusted. The body of the valve for admitting compressed air to the closing cylinder serves as a cylinder head. The valve plug is operated by the valve handle located on top of the spring rod head and connected to the plug by the telescoping valve shaft and sleeve passing through the center of the spring rod. Compressed air is led to the valve through a $\frac{3}{4}$-inch pipe and flexible hose from the air supply system.

The power of the spring and its lever arm are so designed that during the opening of the breech mechanism this is nearly balanced until fully opened, when an extension on the carrier bracket is brought in contact with the head of the spring rod, suddenly increasing the lever arm of the spring, which is thus enabled to take the shock and stop further motion of the mechanism.

505. **To close the breech mechanism,** compressed air is admitted to the closing cylinder by opening the valve by hand. The air pressure on the piston is transmitted through the spring rod to the carrier cam bracket. When the mechanism is nearly closed, the ball on the closing rod comes in contact with the valve closing rod pin, automatically revolving the valve shaft and closing the valve, and at the same time opening a by-pass from the closing cylinder to the atmosphere.

The firing mechanism consists of firing lock Mark XIV Mod. 1 which has been previously described.

CHAPTER XII.

NAVAL GUN SIGHTS.*

Preliminary Definitions.

506. (1) **The axis of the bore** of the gun is its longitudinal geometrical axis.

(2) **The axis of training** of a gun is the axis of motion of the top carriage in azimuth; this axis must be installed so that, when the ship is on an even keel and normally trimmed, it will be perpendicular to the plane of the horizon.

(3) **The axis of the trunnions** is their common geometrical axis; the side must be so machined that this axis will be accurately at right angles with the axis of bore. The adjustment of the frictionless trunnions (or, in the case of small guns, the machining of the trunnion seats) must be such that the axis of trunnions is accurately at right angles with the axis of training. Then, when the ship is on an even keel and normally trimmed, the axis of the bore will move in a plane vertical to the plane of the horizon when the gun is moved in elevation.

(4) **A modern naval sight mount** is a mechanism, attached to or connected to the gun slide, that carries two points, called the front and rear *sight points,* whose positions relative to each other are rigidly fixed. In Plate I, the front sight point S' is the apex of a cone; the rear sight point S is the bottom point of a V-shaped notch; the straight line prolonged through these two points is called the *line of sight.*

(5) **The trajectory** is the curve described by a projectile in passing from the muzzle of a gun to the point of impact; its

* Rear Admiral Bradley A. Fiske, U. S. N., invented the application of the telescope-sight as a permanent part of the gun-mount, in 1892; prior to this telescopes had been used, but they were always removed from the gun before firing.

The development of the telescope as a night-sight was the result of original experiments that were made by Lieutenant Commander H. C. Mustin, U. S. N., while on duty at the Gun Factory in August, 1905. He also designed telescopes Marks XI, XII and XIII (prismatic) in 1905-1906. The other inventions of his referred to in the text are as follows: Periscope sight-mount for turret-guns, in 1904; periscope sight-mount for broadside guns, in 1906; focusing-cap, in 1906.

downward curvature MmI (Fig. 75 elevation) is due to the force of gravity; its lateral curvature MmI (Fig. 75, plan) is due to the rotation of the projectile that is imparted by the rifling of the gun. This deviation from the vertical plane of fire is called the *drift*, and is to the right in all our guns.

(6) **The line of departure** is the tangent to the trajectory at the muzzle of the gun; it is coincident with the axis of bore at the instant the projectile leaves the gun (MM', Fig. 75.)

(7) **The jump** is the small vertical angle, usually upward, which the axis of the bore describes in the act of firing (j, Fig. 75);

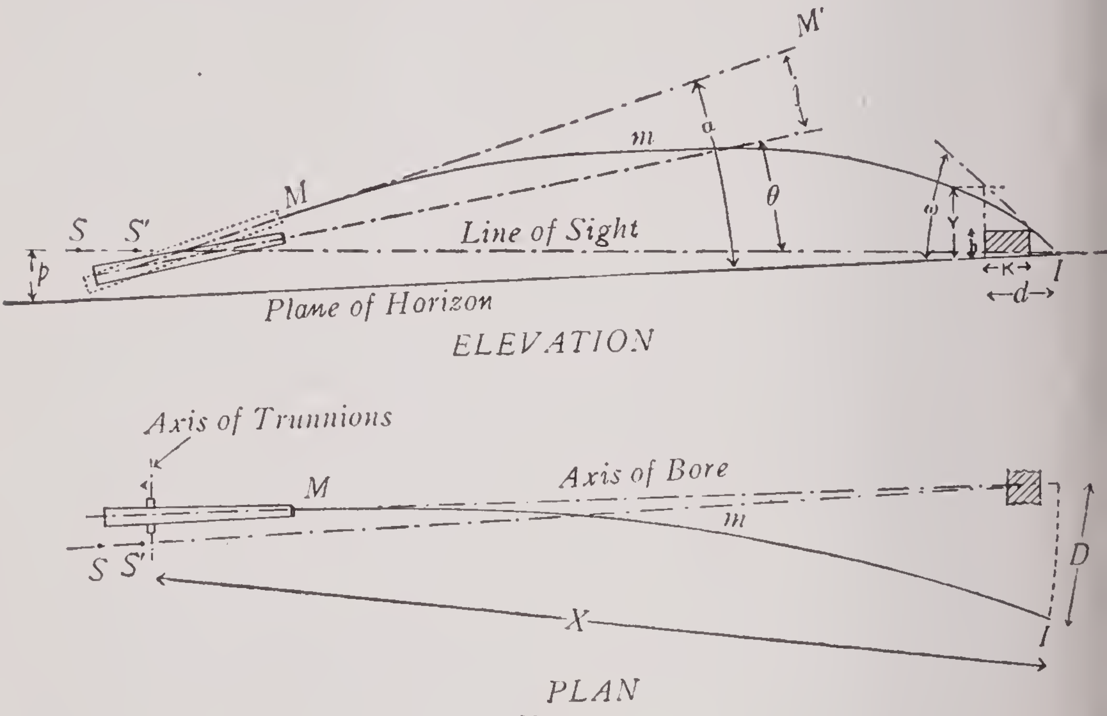


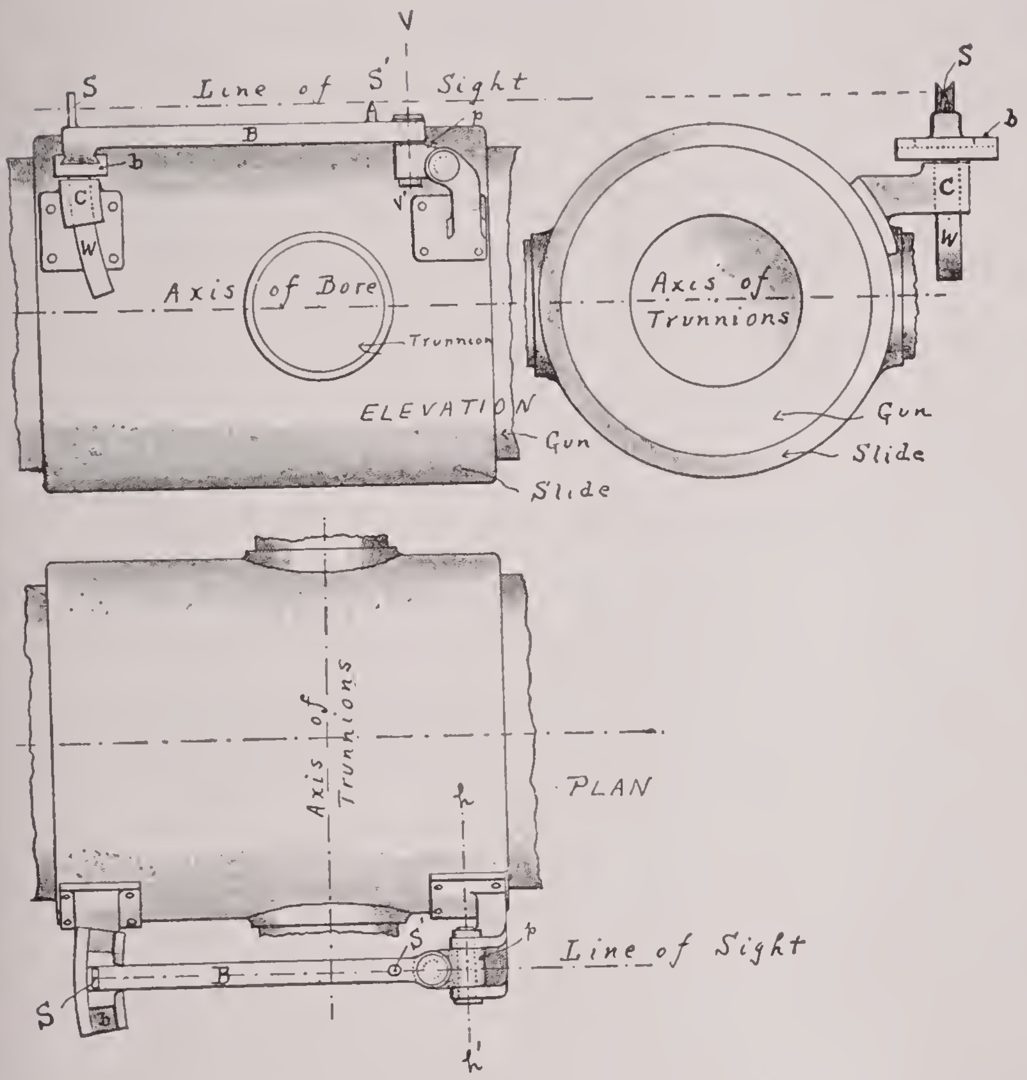
FIG. 75.

it is due to a yielding in the supports of the gun, caused by the shock of discharge.

(8) **The angle of position** for a given target is the vertical angle between the plane of the horizon and the line of sight, when the line of sight passes through that target (p, Fig. 75).

(9) **The angle of elevation** is the vertical angle that the line of sight makes with the plane through axis of the bore and axis of the trunnions (θ, Fig. 75).

(10) **The angle of departure** is the vertical angle between the line of departure and the plane of the horizon (α, Fig. 75). When the jump and angle of position are negligible, as they are assumed



Axis vv' Should Intersect Axis hh'.

to be in naval gunnery, the angle of departure is the same as the angle of elevation.

(12) **The angle of fall** is the vertical angle that the tangent to the trajectory at the point of fall makes with the plane of the horizon (ω, Fig. 75).

(13) **The range** is the distance in a straight line from the gun to the "point of fall." When the point of fall is in the same horizontal plane as the gun, the range is called the "horizontal range." Ordinarily the word "range" is used to designate the "horizontal range."

The word "range" is also used aboard ship to designate the "range-finder range" which is almost never the same as the actual "range." Another use of the word is to signify the "sight-bar range."

The loose usage of this word is to be deplored, and unless it is definitely stated what usage is meant it is only from the context of the subject that it can be determined whether the true "horizontal range," the "range-finder range," or the "sight-bar range" is intended. In actual practice these three ranges are never all the same in numerical value, though fairly close together.

(14) **The danger space** is the distance through which a target of a given height can be moved from the "point of fall" directly toward the gun and still have the projectile pass through the target.

If the "maximum ordinate," or highest point of the trajectory, does not exceed the height of the target the "danger-space" is evidently equal to the range, and such a range is known as the "*danger range*."

If h be the height of the target in feet, an approximate value for the "danger space" is given by the expression

$$d = h \cot \omega.$$

If the target has a beam k feet the approximate danger space will be

$$d = k + h \cot \omega.$$

A more exact formula for the danger space is given by the expression

$$d = h \cot \omega \left(1 + \frac{h \cot \omega}{X}\right).$$

where X is the range in feet.

(15) **The virtual height** of a target is equal to $d \tan \omega$ approx. (Y, Fig. 75).

Fundamental Requirements.

507. All sights must fulfil the following fundamental requirements:

(a) To set the line of sight at any specified angle with the plane through axis of bore and axis of trunnions; for this purpose there is required the *horizontal sight axis hh′*, which necessarily must be installed exactly parallel to the axis of trunnions.

(b) To set the line of sight at any specified angle with the plane through the axis of bore that is perpendicular to the axis of trunnions; for this purpose there is required the *vertical sight axis vv′*, which must be installed exactly at right angles with the axis of trunnions.

The fundamental requirements of a sight-mount are illustrated in Plate I; every modern naval sight, whatever its type may be, is based on principles shown in this figure. The bar which carries the front and rear sight points, S' and S, is called the *pivot bar*.

To meet the first requirement of the mechanism, the *pivot block* p, to which the front end of the pivot bar is attached, engages the shaft whose axis hh' is the horizontal sight axis installed exactly parallel to the axis of the trunnions. Vertical motion is imparted to the pivot bar and to the line of sight by raising the curved bar W, called the *sight bar;* this moves in the casing C, called the *sight-bar bracket*, which has a fixed position relative to the bearings of the horizontal sight axis. The front and rear faces of the sight bar, and the interior front and rear faces of the sight-bar bracket, are machined to arcs of circles centered in the horizontal sight axis. It is evident that the side faces of the sight bar and the interior side faces of the sight-bar bracket must be in planes perpendicular to the horizontal sight axis; otherwise, vertical motion of the sight bar would cause an appreciable lateral motion of the rear sight point, and a consequent deviation in the lateral setting of the line of sight.

To meet the second requirement of the mechanism, the pivot bar engages a pin in the pivot block whose axis is vv', installed exactly at right angles to the horizontal sight axis hh' and intersecting it. Lateral motion is imparted to the pivot bar and to the line of sight by moving the rear end of the pivot bar in a groove in the *azimuth head;* the front and rear faces of this groove and its fitting on the rear end of the pivot bar are machined to arcs of

circles centered in the vertical sight axis. It is evident that the flat contiguous faces of these parts must be in planes parallel to the horizontal sight axis and at right angles with the vertical sight axis; otherwise lateral motion of the sight bar would cause an appreciable vertical motion of the rear sight point and a consequent deviation in the vertical setting of the line of sight.

The means of imparting motion to the pivot bar are, for the sake of simplicity in the drawings, omitted from Fig. 1 and the following illustrations of sight mounts. They are as follows: Vertical motion is given by a *worm wheel*, journaled in the sight-bar bracket, that engages a *worm* on the rear face of the sight bar; the worm wheel is connected by miter gears to a hand wheel which has a small crank handle. Lateral motion to the pivot bar is given by a worm wheel on the azimuth head that engages a worm on the rear end of the pivot bar; the hand wheel for lateral motion is similar to the hand wheel for vertical motion.

Sight Scales.

508. There are two kinds of scales on every sight. One kind indicates the movement of the line of sight about the horizontal sight axis; this is called the *range scale*. The other kind is for indicating the movement of the line of sight about the vertical axis, and is called a *deflection scale*. Sight scales are either *direct reading* or *multiplying;* the direct reading type will be described first.

509. A direct-reading range scale suitable for the sight mount in Plate I is shown in Fig. 76. The *range strip*, made of white metal, is engraved with the divisions and numbers of the scale; it is dovetailed to fit in the *sight bar* flush with the outer side face, and is adjustable within the limits of the elongated hole for the clamp-screw *E*. The arc of a circle *Y* (shown in broken lines), which touches the rear ends of the scale divisions and front end of *K*, the reference mark on the *sight-bar bracket*, is centered in the horizontal *sight-axis hh'* Plate I. This circle gives a basis for laying off the spacing of the scale divisions, which are calculated from data obtained at the proof firing of the gun. The divisions read in yards of range for certain standard conditions as follows:

(a) Atmosphere of unit density.

(b) Powder charge of a certain weight and index that, at a temperature of 90° F., will give a muzzle velocity of a certain number of foot-seconds.

(c) Projectile of a specified weight and coefficient of form.

(d) Force of wind on the range zero.

For the above conditions, the angle of elevation for every range from 100 yards up to that which will be given by an elevation of 15° is computed and laid off on the arc *Y*, measuring from the

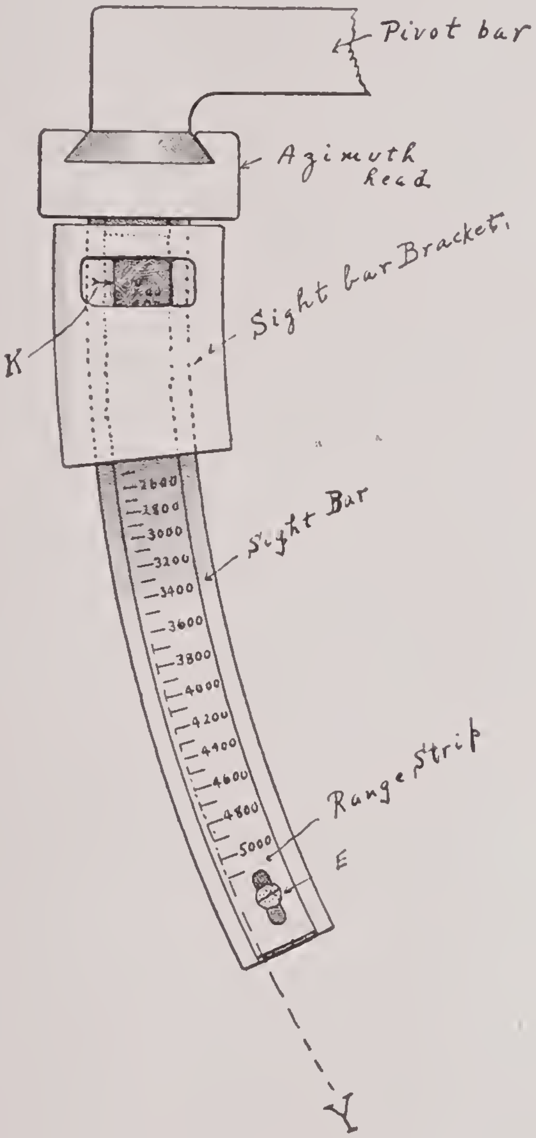


Fig. 76.

zero mark. For instance, under standard conditions, it is determined that a range of 5000 yards requires an angle of elevation of 5° 40′; then an arc of 5° 40′, measuring from the zero division, is laid off, and the division numbered 5000 is plotted.

Adjustments of the zero divisions are two of the details of *bore sighting*—a subject which is described more fully in paragraph 543. A *bore sight* consists essentially of two *sight points* placed accurately coincident with the axis of the bore; by means of these and the elevating and training gears of the gun, we can lay the axis of bore on a certain mark which is at a mean target practice or battle range; then, by motion of the pivot bar we can direct the line of sight to the same mark (Fig. 77).

At present we are interested only in the range scale; this must now be shifted to read zero by shifting the position of the range strip or, as is arranged for in some sight mounts, by shifting the reference mark. After this is done, the gun is said to be bore-sighted in range for the mean range selected. Say this is 5000

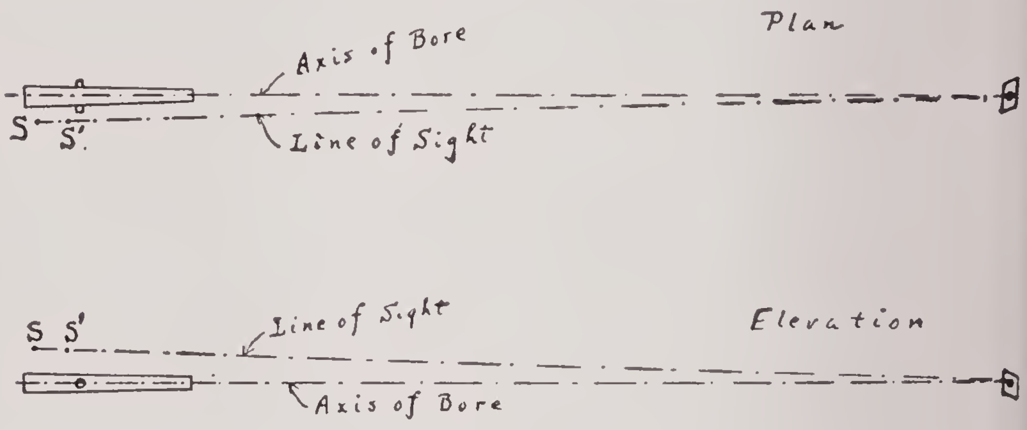


FIG. 77.

yards. Now if we raise the sight bar to the reading 5000, and move the elevating gear of the gun until the line of sight is directed to the target, the gun will be at the proper elevation to give a range of 5000 yards under the standard conditions (a), (b), (c), and (d). Now if the gun is fired under these conditions, from a motionless ship at a motionless target, the projectile will attain a range of 5000 yards; but it will fall to the right of the target an amount D (Fig. 75), which is the drift corresponding to 5000 yards range.

In the above example we bore sighted for a mean range of 5000 yards; it is therefore evident that there will be a small vertical pointing error, when we fire at other ranges, unless we have a sight-mount that has its horizontal sight-axis coincident with the axis of the trunnions. For instance, if the horizontal sight axis is

5 feet higher than the axis of the trunnions—as it is in some turret sight mounts—and we have bore sighted for a mean range of 5000 yards, we shall have a pointing error $2\frac{1}{2}$ feet low when firing at a range of 2500 yards, or we shall have a pointing error of $2\frac{1}{2}$ feet high at a range of 7500 yards. But we are better off than if we had bore sighted by the old method of pointing at a star, and thereby adjusting the line of sight parallel to the axis of bore; this, in the above example, would give us a pointing error of 5 feet low at all ranges.

510. Drift compensation.—The lateral error D, in Fig. 75, due to the drift at a range R, represents an angular error, which is practically $\tan^{-1}\frac{D}{R}$. To compensate this, we move the rear end of the pivot bar to the left through an angle $\tan^{-1}\frac{D}{R}$; then train the gun to the left until the line of sight is again directed to the target

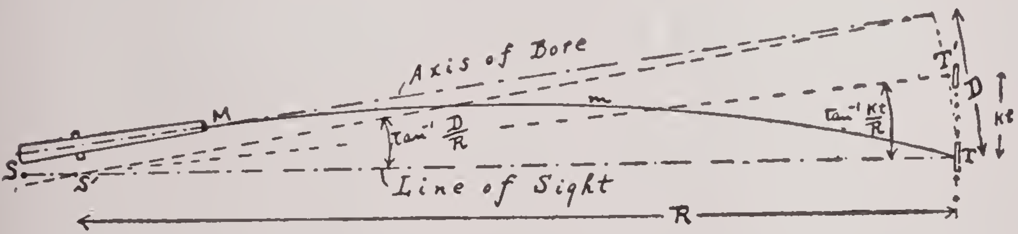


FIG. 78.

T, as shown in Fig. 78. The next shot will be a hit, provided we have the standard conditions (a), (b), (c), and (d), above.

511. A deflection scale is used primarily for making the drift compensation; a direct-reading deflection scale with its mounting, suitable for the sight mount shown in Plate I is shown in Fig. 79.

The *pointer* P is attached to the rear end of the pivot bar by the screws a and b, and is adjustable vertically, with reference to the pivot bar, within the limits of the elongated holes for these screws. The rear surface of the *azimuth plate* is machined to the surface of the toroid that is generated by the lower end of the pointer P when the pivot bar is moved about its two axes; this plate is dovetailed into the sight-bar bracket, and is adjustable horizontally within the limits of the elongated holes for the clamp-screws c and d.

In bore-sighting the gun, after the range strip has been shifted to read zero, the next step is to make the deflection scale read zero.

First, raise or lower the pointer *P*, with reference to the pivot bar, until the lower end of the reference mark is on the level of the zero mark on the azimuth plate; then shift the azimuth plate to the right or left until the center of the zero mark is at the lower end of the reference mark. Fig. 79 shows the sight bar raised to the reading 1000 yards after range- and deflection-scale adjustments have been made; the lower end of the reference mark is now

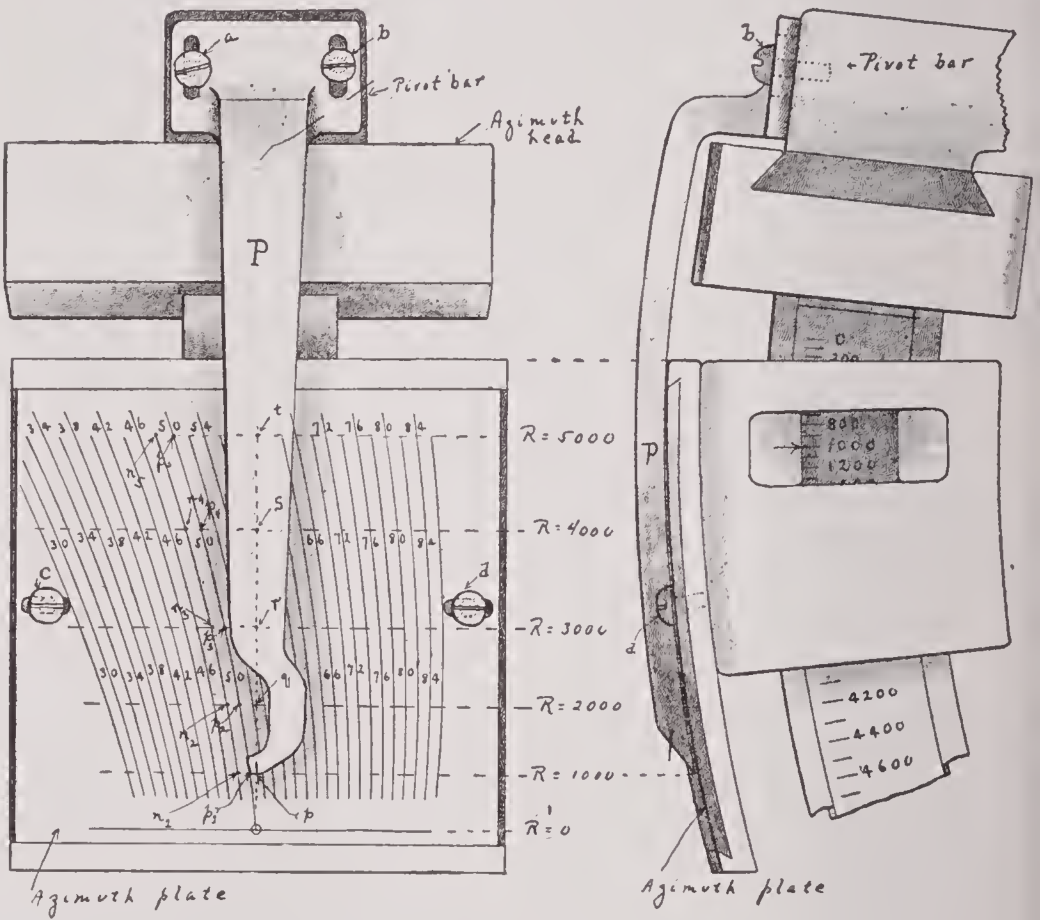


FIG. 79.

at the position p; its position for ranges 2000, 3000, 4000, 5000 would be q, r, s, t, respectively, if no lateral motion is given to the pivot bar. Now, if we move the rear end of the pivot bar to the left from the position p through an arc $pp_1 = \tan^{-1}\dfrac{(\text{drift at } 1000)}{1000}$ to the position p_1, we shall have compensated the drift at 1000 yards range as in Fig. 78. Similarly, we can locate the points p_2, p_3, p_4, p_5, etc., by laying off the arcs, qp_2, rp_3, sp_4, tp_5, etc., which correspond respectively to the drift at ranges 2000, 3000, 4000,

5000, etc., and can lay down a fair curve through the zero mark and the points p_1, p_2, p_3, p_4, p_5, etc. When the sight bar is raised to any range reading and the pivot bar is moved to the left until the reference mark on the pointer touches this curve, a shot fired under the standard conditions (a), (b), (c), and (d), Art. 509, will have no drift error. This curve was formerly called the *zero line*, but now, for convenience in sight setting (as will appear later), it is called the *fifty line* and is numbered as in Fig. 79.

512. Speed compensation.—Thus far we have considered the ship and target motionless, but, in naval gunnery, either the target or ship or both are steaming ahead. We will examine the case of firing from a stationary ship at a target steaming at a speed of k knots per hour on a course at right angles to its bearing; we assume that there is no breeze, and that we have standard conditions in the atmosphere and ammunition.

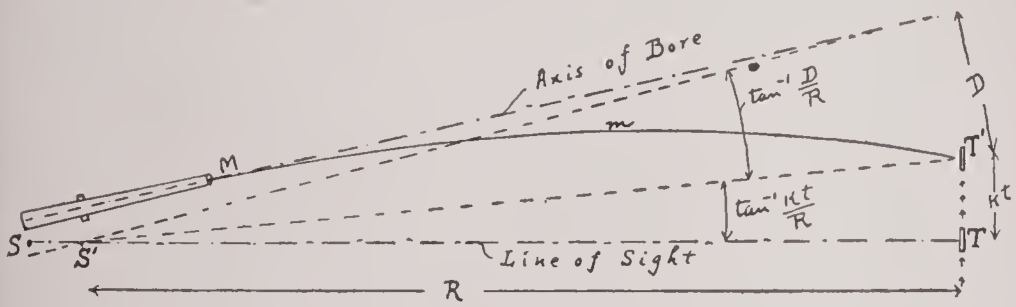


FIG. 80.

In Fig. 78, $SS'T$ is the line of sight, MmT is the trajectory, R is the range; the sight has been set in azimuth with deflection pointer touching the fifty line, so the drift is compensated. T is the position of the target at the instant of firing, and t is the time of flight of the projectile for the range R. The shot will fall to the right of the target; for, during the time of flight, the target has moved to the piston T'. The lateral error is $TT' = kt$, and the angular error is $\tan^{-1} \frac{kt}{R}$. To correct this error we move the pivot bar to the left through an angle $\tan^{-1} \frac{kt}{R}$, which gives the condition shown in Fig. 80.

In the above example, we will assume the range is 1000 yards, the time of flight is t_1 and the speed of the target is two knots per hour. Then, laying off on the azimuth plate in Fig. 79, the

arc $p_1n_1 = \tan^{-1} \frac{2t_1}{1000}$, we locate the point n_1; when the pivot bar is moved to the left so that the reference mark on the deflection pointer is at the position n_1, the sight will be set for compensating the speed of two knots in the example given. Similarly, for ranges 2000, 3000, 4000, etc., and corresponding times of flight t_2, t_3, t_4, t_5, etc., we locate the points n_2, n_3, n_4, n_5, etc., and can lay down a fair curve through these points and n_1; then, when the sight bar is raised to any range and the pivot bar is moved to the left until the reference mark touches this curve, the error due to two knots speed will be compensated when the target is moving in the direction shown in Fig. 80. The curve for compensating two knots speed when the course of the target is in the opposite direction, is plotted by laying off arcs equal to p_1n_1, p_2n_2, p_3n_3, p_4n_4, p_5n_5, etc., to the right, instead of to the left, of the fifty line. The other speed lines shown in Fig. 79 are computed in the same manner, using the proper values of speed, range, and corresponding times of flight. The method of numbering the lines shown in this figure obviates the use of the words "right" and "left" in designating the setting of the sight in azimuth. This avoids the errors that formerly were frequent on account of confusing right with left; it also simplifies the visual fire-control instrument, because the indication for the azimuth setting requires only two numerals, instead of two numerals and the designation "right" or "left."

513. **Sight radius.**—The length from the center of the vertical pivot, *V*, Plate I, and Fig. 99, to the center line of the "azimuth head," or the distance between the front and rear sights in open sights as in Figs. 86 and 90 is called the "*sight radius*." Knowing the sight radius, we are able to obtain definite values for these arcs by spacing off the distances between the drift curves on the azimuth plate (Fig. 79).

Assume that we are firing a 12-inch gun having an initial velocity of 2900 foot-seconds at a target 1000 yards distant and moving at two knots speed (3.38 foot-seconds). By referring to the 12-inch 2900 foot-seconds range table (column 4), we find that for a range of 1000 yards the time of flight is 1.05 seconds. Let the sight radius of the gun equal B inches, and let x equal the length in inches to lay off on the azimuth plate to compensate for the speed of the target.

3.38 feet $\times$ 1.05 (time of flight) $=3.549$ feet, the distance the target will steam at 2 knots in the time of flight of the projectile. Then from similar triangles, considering $OT=OT'$ and $OS=OS'$,

$$B:R=x:D,$$

$$B \text{ in inches}: 3000=x:3.549,$$

$$x=\frac{3.549B}{3000}.$$

Let us give B a value of, say, 100 inches. Then $x=.118+$ inch.

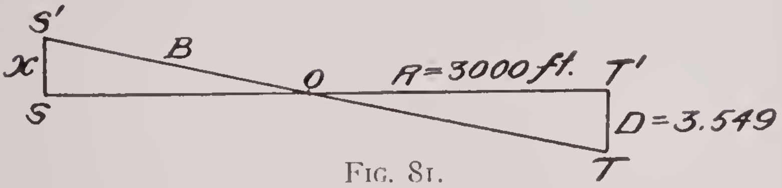


FIG. 81.

By the same method for 3000 yards range, we find $x=.123$ inch; for 5000 yards range, $x=.127+$inch. Working it out for longer ranges, we get gradually increasing lengths of x, which illustrates why the drift curves are close together at the bottom of the azimuth plate and wider apart at the top.

514. Azimuth plates are marked in knots for speed of target. This is obviously the right method, as will be seen. Let us try to mark the azimuth plate for speed of ship, the target being stationary. Assume the ship steaming ahead at 2 knots speed, firing

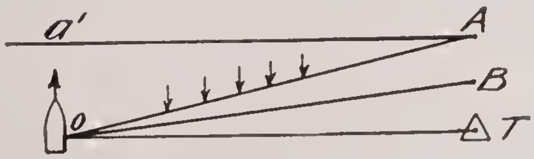


FIG. 82.

at the target T. The speed of the ship will give to the projectile a component in the direction of motion of the ship equal to 2 knots per hour, which, if the firing were in vacuum, would cause the projectile to fall at A, and $AT=Oa'$, the distance the ship would steam in the time of flight. However, we are not firing in vacuum, but in still air, and the projectile would be driven to the right by an apparent wind of 2 knots per hour, which would begin to act as soon as the projectile left the gun, and its effect would increase with the range. Therefore the projectile would fall at B. (Fig. 82.)

Referring to the 12-inch range table, we find that for a range of 1000 yards the effect of the apparent wind on a 12-inch shell would be practically negligible; the firing ship would advance $1\frac{1}{6}$ yards, and the shell would be deflected to the left $1\frac{1}{6}$ yards. (As a matter of fact, the shell would feel the effect of the apparent wind; but at this short range we can neglect it.) At 5000 yards range the firing vessel would advance $6\frac{1}{3}$ yards; the shell would miss the target by $5\frac{5}{6}$ yards. The difference, $\frac{3}{6}$ yard, is the effect of the apparent wind on the shell during the time of flight. At 10,000 yards range the firing ship would advance 14 yards; the shell would miss the target by $11\frac{2}{3}$ yards. The difference, $2\frac{1}{3}$ yards, is the effect of the apparent wind during the time of flight. In every case, in order to know the number of yards to be allowed for speed of ship, we should necessarily take into account the effect of the apparent wind, which varies with the strength of the wind and the time of flight. The target, however, during this time of flight, steams a certain definite distance which is dependent on no other elements. It is thus much simpler to mark the azimuth plate for speed of target than to mark it for speed of ship.

If the target is speeding at 10 knots at right angles to the line of fire, we set the deflection scale at 50 ± 10, to compensate for the speed of the target. If the target is anchored and the firing ship is steaming at 10 knots speed at right angles to the line of fire, the setting of the deflection scale would be $50 \pm (10 - \text{effect of the apparent wind})$. This can be readily obtained from the range tables.

515. Azimuth errors.—The speed curves on the deflection scale shown in Fig. 79 are accurate only under the following circumstances: (a) When there is no breeze on the range, (b) when we have standard conditions in ammunition and atmosphere, and (c) when we fire from a stationary ship at a target steaming on a course at k knots per hour at right angles to its bearing.

The error that arises if the deflection scale be set for the full speed of the target when the course of the latter is at an angle C with its line of bearing is shown in Figs. 83 and 84. In these figures R is the range at the instant of firing; t is the time of flight for that range; T is the position of the target at the instant of firing; T' is its position at the instant of impact. It should be noted in both figures that an error in range as well as an azimuth

error is introduced. In both cases the sight is over compensated in azimuth.

In the first case the target is steaming partly with the direction of motion of the projectile, and in the second case partly in the opposite direction. Since the distance the target steams in the time of flight is small in comparison with R, we can say without much error that there has been no change in range. But since we are now dealing only with azimuth errors, we are interested in

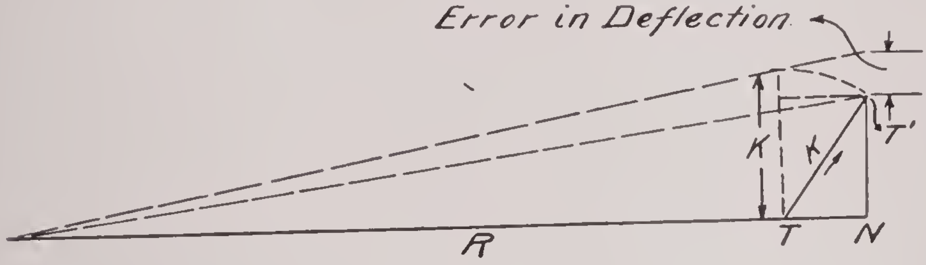


FIG. 83.

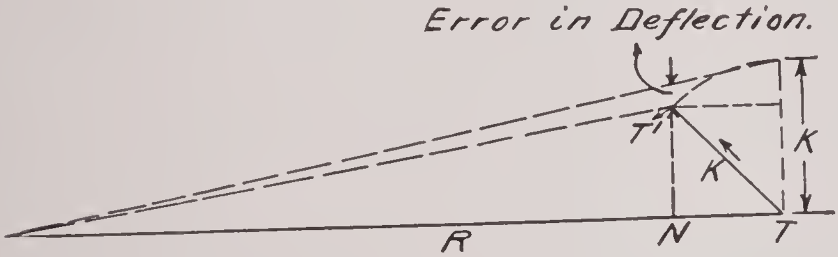


FIG. 84.

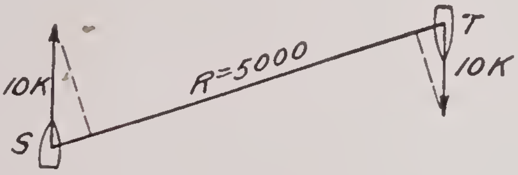


FIG. 85.

obtaining the component of the target's speed at right angles to the line of bearing, in order to know the azimuth setting. In both cases it is $T'N$, which is equal to $k \cos C$; and the setting of the deflection scale should be $50 \pm k \cos C$.

When both ship and target are moving.—Let us assume the firing ship S (Fig. 85) is steaming at 10 knots on course North, and the target ship T 10 knots on course South, and that at commencement of firing with 12-inch guns the target ship bears 60°

on the starboard bow of the firing ship. The combination setting is the algebraic sum of the compensation for speed and course of the target and for speed and course of the firing ship. If there is no breeze, that part of the setting involving speed and course of the firing ship will be in error by reason of the effect of the apparent wind component. If there is a breeze, both parts of the compensation may be in error. The setting of the deflection scale will be:

$$\text{Due to target ship:}\quad 50+10 \sin 60^\circ = 58.7$$
$$\text{Due to firing ship:}\quad 50+10 \sin 60^\circ = 58.7$$

Therefore, if the deflection scale is set at $50+17.4=67.4$ the compensation is made; but it is in error because we have neglected this effect of the wind component on the shell.

To get the true azimuth setting we would proceed as follows: Referring to the 12-inch 2900 foot-seconds range tables, 5000 yards range.

Due to target ship:

Lateral deviation to left of target, $\frac{8.7}{12} \times 38$ (col. 18) $=27.6$ yards.

Due to firing ship:

Lateral deviation to left of target, $\frac{8.7}{12} \times 35$ (col. 17) $=25.4$ yards.

Total, 53.0 yards.

This is the number of yards the shell would miss the target laterally if the gun were fired with the deflection scale set at 50.

From the range tables (column 18) we find that 3.17 yards at the target at 5000 yards range is corrected by one division on the deflection scale. Dividing by 3.17 the total number of yards to be compensated, we get the total number of divisions to the right of the fifty line that the deflection scale must be set in order to make a hit. This is 16.4, which, added to 50, gives the setting, 66.4.

The initial azimuth setting should be as close an approximation as it is possible to make, considering all the elements affecting it, in order that the lateral deviation of the fall of the shell may be as small as possible. The smaller this error, the easier it is for the spotter to bring the next shot on the target.

516. Range errors.—Even when we have standard conditions in ammunition and the atmosphere, it will be evident, from the

preceding article, that when either the ship or the target is steaming there will be a range error in the fall of the shot. Under the usual conditions of battle, where the differences in course and speed of ship and target are not large, this error will probably be less than the danger space. A wind component in the plane of fire will decrease or increase the range according as it is towards or away from the ship. This error is comparatively small; for instance, with the 12-inch gun, when the target is distant 9000 yards, a wind component of 12 knots in the plane of fire will cause a change of 21 yards in the range. (See column 13, Range Table, 1912.)

Range errors due to variations from standard conditions are as follows:

(a) *Change of range caused by variation of the density of the atmosphere.*—A density above unity, the density for which the range strip is calculated (barometer 29.53 inches, thermometer 59° F.), will make the shot go short; density below unity will make the shot go over; other conditions being normal. For instance, a variation of 5 per cent will make a change in range of 87 yards at 9000 yards range with the 12-inch gun. (See column 12, Range Table, 1912.) This is an error that can be foretold by observation of the barometer and thermometer (outside) immediately before firing; if the change of distance of the target is not to be considerable, it can be satisfactorily compensated by applying a correction to the initial sight-bar range equal to the error picked out for the mean distance of the target. But as the error for a given density of the atmosphere varies with the range, it is evident that this method of compensation fails when there is a wide change in the distance of the target during the firing.

(b) *Variation in the range caused by variation in the temperature of the powder.*—Temperature of the charge above 90° F., the standard for which the range strip is calculated, will make the shot go over; and temperature below 90° will make it short. This is an error that can be avoided by keeping the magazines at the standard temperature by means of refrigeration or heating. On ships where these appliances are not installed, the worst feature of the temperature error is that magazines in different parts of the ship, for guns of the same caliber, will have different temperatures, and so the guns they supply will have different range errors. For

instance, if the forward 12-inch magazine has a temperature of 93° and the after 12-inch magazine has a temperature of 87°, when the target is distant 9000 yards, the forward 12-inch guns will shoot 53 yards over, while the after 12-inch guns shoot 53 yards short. (See column 10 and explanatory note in Range Table, 1912.) Here is a difference amounting to more than half the danger space of 20-foot target-screen (84 yards at that range); consequently one turret may be hitting at the base of the target while the other is firing over the top edge. We must therefore apply corrections to the initial range to each gun in accordance with the temperature of the magazine that supplies it; and, since the temperature error varies with the distance of the target, we must select the correction for the mean range expected. If there is not much variation in the distance from this mean, this method of compensation will be satisfactory.

(c) *Change of range caused by variation in weight and coefficient of form of the projectile.*—A projectile of different weight from that for which the range strip is calculated will fall short if over weight, or will fall over if under weight. For instance, a 12-inch projectile 5 pounds under weight will fall 20 yards over when the target is distant 9000 yards. (See column 11, Range Table, 1912.) Where the projectile is of standard weight, but is of a coefficient of form different from that for which the range strip is calculated, the trajectory will differ in range and drift. The new long-pointed projectile has a flatter trajectory than a blunt-pointed projectile of equal weight. Of late the inspection of projectiles before issue to the ship has become so reliable that errors in the weight need not be expected. When projectiles of different coefficients of form are supplied, range and deflection strips for each kind are furnished.

517. Arbitrary deflection scales.—The method of marking the deflection scales of sights in knots as described above is no longer used, but an understanding of this method is necessary before the method of "arbitrary" divisions, which is the modern practice, can be understood.

The method of controlling deflection by means of "deflection boards" and "arbitrary scales" was devised for the purpose of relieving the sight setters of the responsibility of keeping the deflection pointer on a designated deflection curve. The principle

upon which the method is based is in no way different from the standard method of controlling deflection by means of knot curves. It differs in the method of application, in that one curve sheet upon which the knot curves are drawn performs the functions of the curve drums formerly fitted upon each individual sight. Many of the sights still in service are adapted for the use of either method of deflection control, and it will be seen by trying both methods that they give the same results, regardless of which one is used.

The method of bringing the point of impact on the target in deflection in no way differs from that of bringing the point of impact on the target in range, except that deflection correction controls the angle of the sight with respect to the axis of the gun in the horizontal plane, while range correction controls it in the vertical plane. If the point of impact be short of the target, or, in other words, too low, the sight is raised; if the point of impact is to the left in deflection, the rear end of the telescopic sight is moved to the right, and vice versa. In either case it is the angle between the axis of the telescope and the axis of the gun that is changed, for range in the vertical plane, and for deflection in the horizontal plane.

To arrive at a clear understanding of the principle of deflection, it should be comprehended that all deflection measurements can be reduced to angular measurements. If the horizontal angle between the axis of the gun and the line of sight be the same for all the guns of the same caliber firing, then the corresponding deflection, whether measured in knots or in yards, will also be the same for all those guns. It is thus seen that the sights for all types can be so constructed that the unit of measurement for deflection is an angle.

Principle of Arbitrary Scales.

518. In the method of controlling deflection by the use of "deflection boards" and "arbitrary scales," the unit of measurement, that is, the angle corresponding to one division of the scale, is the angle that is subtended by one-half of a chord of 0.2 of an inch at 100-inch radius; that is, it is the angle whose tangent is .001. By using this unit of measurement, the divisions on the arbitrary scale (*G*, Plate II), are all equal to 0.1 an inch on all deflection boards for all sights for all guns, and all deflection boards are therefore

uniform in construction. The arbitrary scale fitted to each sight is graduated so that one division of the sight scale corresponds to this standard angle, whatever the value of the sight radius, and the actual magnitude of each such division in fractions of an inch therefore depends upon the value of the sight radius, and is determined from it by proportion, as follows:

$$\frac{x}{l} = \frac{0.1}{100}, \text{ whence } x = \frac{l}{1000}$$

where x (in fractions of an inch) is the magnitude of the arbitrary division, and l is the sight radius in inches. These arbitrary scales, when once graduated, become permanent, regardless of any change in initial velocity or other modifications affecting the trajectory. The necessary corrections to provide for a change in initial velocity, for instance, would be made on the curve sheet (*J*, Plate II), and expensive and troublesome modifications in the manufactured scales on the sights would therefore be unnecessary. As the above-mentioned curve sheets are made on drawing paper, quickly and at small cost, it will be seen that changes in the ballistics of the guns could be made without great expense or delay in the supply of the necessary means for deflection control.

In the triangle under consideration, the " side opposite " to the angle adopted as the standard angular unit of deflection, that is, the angle whose tangent is .001, is sometimes known as a " mill," because the side opposite is always one one-thousandth part of the side adjacent. In this case it is therefore the angle that corresponds to a deflection of 1 yard at 1000 yards range, and to a deflection of 10 yards at 10,000 yards range, etc.

General Description of the Sight Deflection Board.

519. The " sight deflection board," as shown on Plate II, as furnished to ships, is simply a means of mechanically turning a determined deflection in knots into the units of the arbitrary scale, and at the same time applying the drift correction for the given range. It consists of a wood or aluminum board, *A*, about 20 inches square. On each side is a rack, *B*, which is secured by wing nuts, *C*. Across the top, and also held by the wing nuts *C*, is a metal strip, *D*, which carries the sliding pointer, *E*. The scale of arbitrary divisions, *G*, slides up and down the board parallel to

itself upon the racks, *B*, as guides. A pinion on each end of the shaft, *F*, runs upon the racks, *B*, and prevents canting of the scale, *G*. The sliding pointer, *H*, is carried upon the scale, *G*, for use in keeping track of the divisions of the scale used. The curve sheet, *J*, is cut to fit under the racks, *B*, where it is held from slipping, after being properly adjusted, by the wing nuts, *C*. In placing the sheet on the board, it must be so adjusted that the reference line, *XX*, will always be under the "50" mark of the scale *G* as the latter is run up and down from top to bottom of the board. (It will be noted on the plate that the line *XX*, which should intersect the 50 curve at zero yards range, is slightly to the right of that curve at the 1000-yard range mark at the top of the curve sheet, which is of course as it should be. The slight divergence of the 50 mark of the scale *G* from the line *XX* that is noticeable on the plate is undoubtedly due to parallax in taking the photograph, the camera apparently not having been set up directly in front of that point.)

The legend on the curve sheet shows for what sights, for what caliber of gun, and for what initial velocity it is to be used; and also indicates, for the information of the spotters and sight setters, the value in knots at some given range to which the divisions on the arbitrary scale correspond.

Method of Use.

520. The deflection board is designed primarily for use in the plotting room, but it can be used at any other point that may be desired, such as the spotter's top or in the turrets.

When about to open fire, the knot curve to be used should be determined by computation (or by the use of the gun error computer) in the same manner as has been explained for the deflection sight scale marked in knots; but this would no longer be sent out to the guns as the setting of the sights in deflection. Instead, the pointer *E* is placed at the top to indicate the curve to be used (the 45-knot curve on Plate III). The scale *G* is then run down the board to correspond to the range to be used (14,000 yards on the plate). The pointer *H* is then run along the scale *G* until it is over the proper curve on the sheet (45 knots), and the reading under the same pointer on the scale *G* will then be the number of divisions of the arbitrary sight scale at which the sights should

be set to give the desired deflection (40 divisions on the plate). As the curves on the sheet are the drift curves for the gun, the sight setting in arbitrary divisions of the scale thus found will of course include the drift correction.

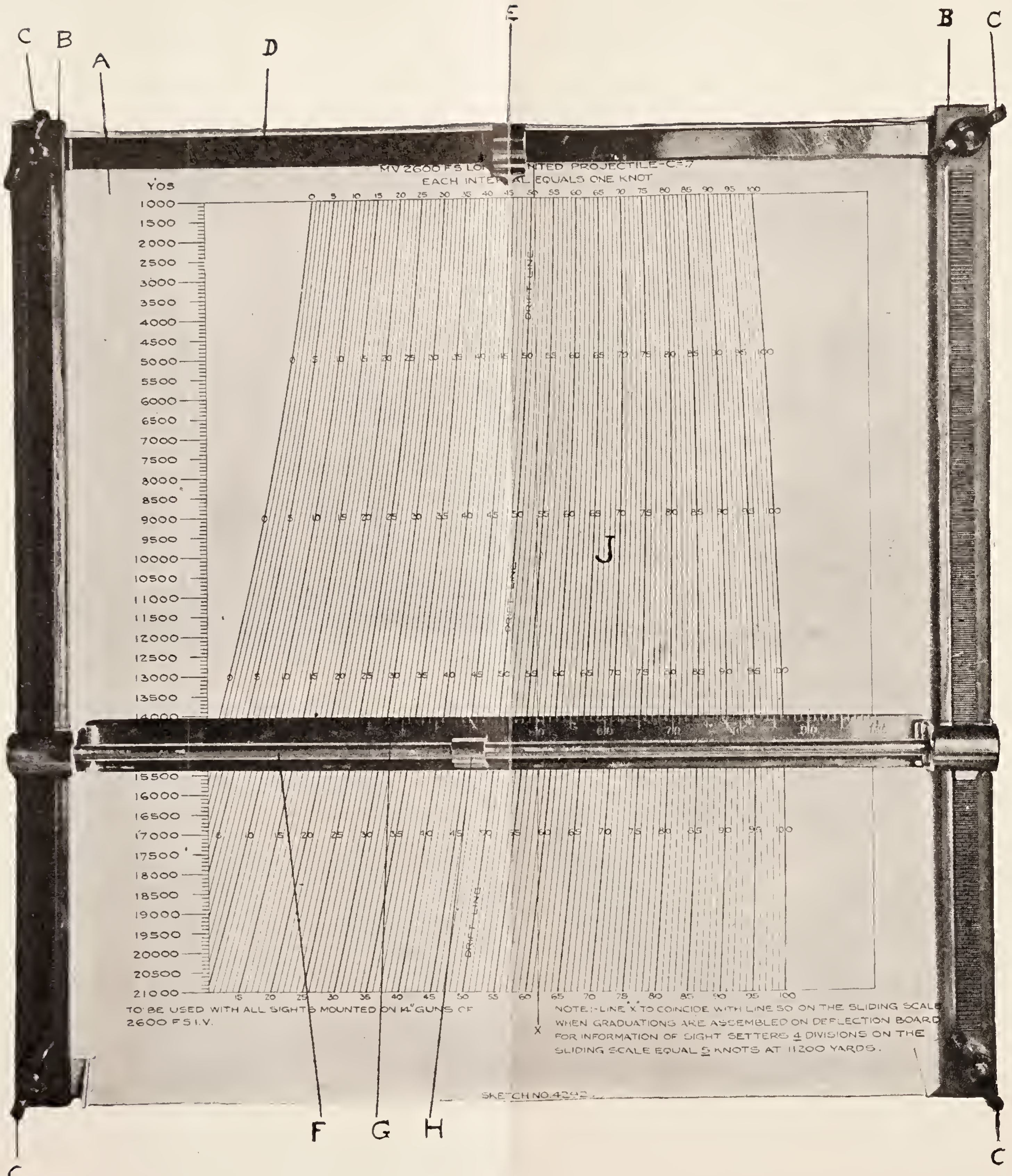
As the range varies during the firing, the scale *G* is moved up and down to follow it, and the pointer *H* is moved to the right or left to keep it over the proper curve on the sheet (45 on the plate). The pointer *H* will then always indicate on the scale *G* the proper sight setting in deflection in the markings of the arbitrary scale.

In case the spotter's corrections indicate the use of a new curve at any time, the pointer *E* is shifted to that curve, and the new readings for the arbitrary scale are read off from the scale *G* by the pointer *H* (which is now following the new curve) and sent to the sight setters.

By this process the sight setters are relieved of all responsibility in regard to the deflection setting other than that of setting the sight for the scale readings which they receive from time to time from the deflection operator, and it is no longer necessary for them to be continually following a drift curve on the sight drum as the range increases or decreases.

521. The method of control described above involving the use of the board gives greater accuracy than the one using curve drums on the sights, as the deflection board permits the curve sheets to be made on a larger scale. It is not necessary, however, to continue the use of the deflection board after the initial data has been obtained for opening fire. The board may be used to determine the setting of the sights in deflection by the arbitrary scale for firing the first shot; and after that the spotter can indicate the deflection changes in terms of the arbitrary scale, providing he knows approximately the value of the arbitrary divisions in knots or yards at the target, for the approximate range at which the firing is being conducted (in yards, this is one one-thousandth of the range in yards, as already seen); and, after shots are seen to be hitting at the proper point, they can then be held at that point by giving the spotter's corrections in terms of the arbitrary scale, as soon as the point of impact appears to creep to the right or to the left, and before it can creep off the target.

522. Multiplying scales.—With high-power guns it is often impracticable to design the pivot bar long enough for distinct



DEFLECTION BOARD.

spacing and numbering of the range divisions at 100-yard intervals and the deflection divisions at 2-knot intervals. In such cases the range scale is placed on a dial geared up from a rack on the sight bar, and the deflection scale is placed on a drum geared up from a rack on the rear end of the pivot bar; this amounts to a mechanical magnification of the scales. As the details of the various methods of accomplishing it are readily understood upon examining the sight mount, no illustrations are given.

In sights of this type great care must be taken to keep lost motion out of the multiplying gears; this would result in sight setting errors in range or in deflection, or in both. Such errors are detected as follows: Lay the gun by the bore sight on some fixed mark; then move the rear end of the sight bar up and to the right until the line of sight is directed to some other point whose position with reference to the first mark is fixed; note the exact reading of range and deflection scales. Now run the sight bar well up above, and move the pivot bar well to the right of these readings; then by motion down and to the left come back to the noted readings. See that the axis of bore is directed to its mark; then, if the line of sight is not directed to its mark there is lost motion between the pivot bar and the scales. The errors may be due to any of the following causes:

(a) Lost motion in the multiplying gear.

(b) Bending of the sight bar, due to very tight fitting of sight axes.

(c) Play in the front end of the sight bar, due to loose fitting of the sight axes.

The above test, in the case of parallel-motion sight mounts, should be made in dry dock or in still water with the ship moored to the dock unless both marks can be set up on the ship; the reason for this will appear later when that type of turret sight mount is described.

523. The calibration of a gun is determined by firing a string of accurately aimed shots at a target bearing nearly abeam, whose distance, at a mean battle range, is accurately measured. The point of fall of each shot is plotted as accurately as possible. The setting of the sight is the same for each shot, making the sight-bar range the same as the actual range; and care is taken that there are no errors in the adjustment or in the mechanism of the

sight mount, or in the adjustment of the telescope. Prior to this the graduations of sight strips should be checked up. The ship is moored in still water and normally trimmed; the powder is all of one index and is kept at the same temperature for each shot of the string—preferably as near as possible to 90°; the projectiles are brought to standard weight if any variation is found; and the density of the atmosphere is carefully recorded throughout the string. The mean force and direction of the wind on the range are determined as well as possible, but on account of the difficulty in getting reliable data of this kind, the firing should be done in nearly calm weather.

After applying to the mean point of impact the corrections for height of bull's-eye from the water, variation from standard density of atmosphere, variation from standard temperature of powder, and the effect of a wind component in the plane of fire, and across the plane of fire, there will still be found a discrepancy between the setting of the sight in range and azimuth and the mean point of impact. A small part of the discrepancy may be due to unlevel installation of the gun mount or improper adjustment of the frictionless trunnions, either of which will produce "tilting" of the line of sight and consequent vertical and lateral errors. These two errors can now be compensated by shifting the range and azimuth strips; for example, we find that the mean point of impact for a string of four shots at a target distant 7500 yards is 250 yards over and 25 yards right, the sight being set to range 7500, deflection 50. Correcting the observed mean error for the height of bull's-eye and the variations from standard conditions, we find the standard error is 100 yards over and 12 yards right. To calibrate this gun in range we would lower the sight bar to reading 7400, then shift the range strip to make it read 7500. To calibrate the gun in azimuth we would set to the fifty-line (when range reads 7500), then shift the azimuth scale to the left the number of knots corresponding to 12 yards lateral error at 7500 yards range. (For instance, with 12-inch guns, column 18 of Range Table, 1912, gives 60 yards deviation for 12 knots; then 1 knot corresponds to 5 yards and 2.4 knots correspond approximately to 12 yards.)

Calibration errors of different guns of one caliber will usually be found different; when each has had its correction applied, all

guns of this caliber will bunch their shots well, when the target is at a distance that does not differ greatly from the distance of the calibration target and when its bearing is about the same, relative to the ship, as the bearing of the calibration target. A change of index of powder from that with which the calibration tests were made will make but little difference in the results, provided the powder is in good condition.

When calibrating a ship's battery, one gun is selected as the standard gun. This selection is made because its standard error is small and because the four shots from the gun have given the most consistent results. The errors of the other guns are compared with the standard gun, and the sights are changed to bring all the guns to the standard gun, after which all the guns will bunch their shots—which is what we strive for in naval gunnery.

Types of Sights and Sight Mounts.

524. The line of sight was defined in paragraph (4), Art. 506, as the straight line prolonged through the front and rear sight points. There are three principal arrangements for establishing these sight points, any one of which may be applied to the sight mounts described in this chapter. These arrangements are named: (1) The *open sight,* (2) the *peep sight,* and (3) the *telescope sight.*

525. The open sight is the earliest and least efficient arrangement of the sight points. As shown in Fig. 86, the *front sight point* is the apex of a cone and the *rear sight point* is the bottom point of a V-shaped notch. (Also see Plate I.)

The chief defect in the open sight lies in the fact that the eye cannot simultaneously see the target and the two sight points distinctly; it must accommodate (focus) successively for three different distances. This sight is not only fatiguing to the eye but is inaccurate even under the most favorable conditions (namely, when both gun and target are still, and there is no difficulty in keeping the optical axis coincident with the line joining the sight points); this is because changes in the direction and intensity of the illumination of the front sight point will make an apparent change in its position and a consequent apparent change in the direction of the line of sight. In addition to the above, there is no magnification of the target, and a considerable portion of its area is obscured by the sight points. This type of sight is rapidly

disappearing from the service, and its use probably will soon be restricted to revolvers and automatic pistols.

In Fig. 86 it will be seen that there is no pivot bar. The *sight bar* is straight, instead of being machined to an arc of a circle. The compensation for drift is accomplished (approximately) by fitting the *sight-bar bracket* so that the sight bar is inclined slightly

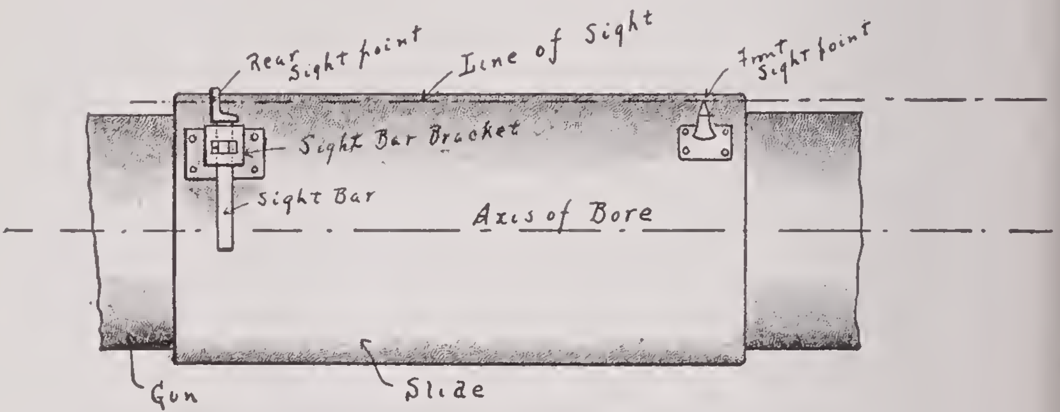


FIG. 86.

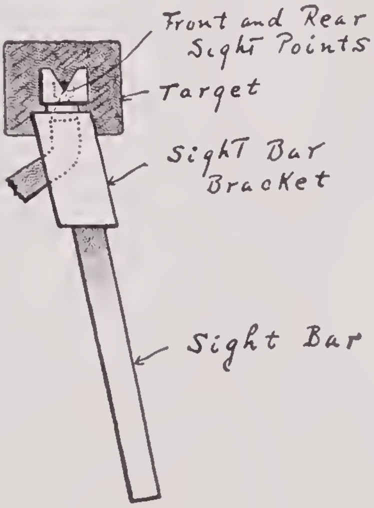


FIG. 87.

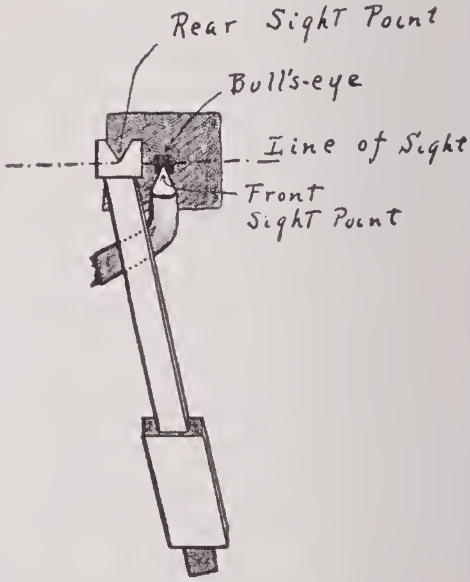


FIG. 88.

to the left at a *permanent angle.* This is illustrated in Figs. 87 and 88. In Fig. 87, with the sight bar at zero, the front sight, rear sight and bull's-eye are in line; in Fig. 88, with the sight bar raised and the gun elevated until the two sight points and bull's-eye are in one plane, it will be seen that the line of sight is pointing to the right of the bull's-eye. Now, to bring it on, we must train the

gun a little to the left, which in a measure will compensate the right-hand curvature of the trajectory.

In sights that are inclined to the left at a permanent angle to compensate for drift, the drift is over-compensated at short ranges and under-compensated at long ranges. In the installation of sights of this character it is assumed that the drift is proportional to the range, which, however, is not the case, as the rate of increase of the drift increases with the range.

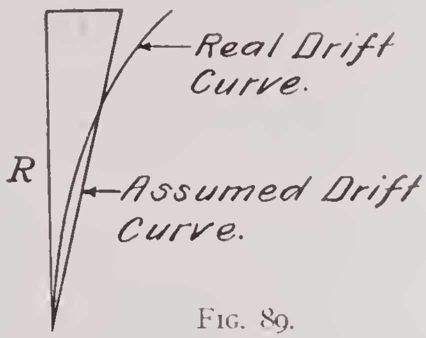


FIG. 89.

526. **The peep sight** is an improvement on the open sight, for the reason that it requires the eye to focus successively for two distances instead of for three. Fig. 90 shows the essential parts of this type of sight.

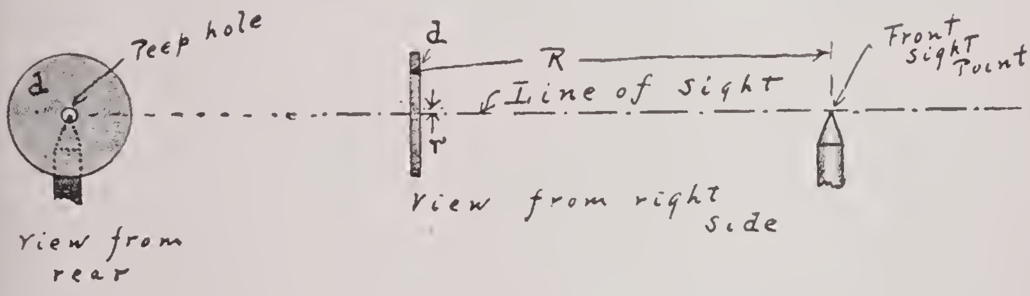


FIG. 90.

The front sight point in a peep sight is about the same as in an open sight; but instead of a notch for the rear sight point there is a circular hole in a *diaphragm* (d, Fig. 90). The line of sight is defined by the tip of the front sight point and the center of the peep hole. It is evident that the accuracy of this type of sight depends primarily on the accuracy with which the eye is centered at the peep hole; if r be the radius of the hole and R be the distance between it and the front sight point, by moving the axis of the eye from the center of the hole over to the edge we shall make

an angular error, called *parallax,* in the line of sight that is equal to $\tan^{-1}\frac{r}{R}$. Now the value of r determines the sectional area of the pencils of light from the target that reach the eye. Since the apparent brightness of an object of a given intensity of illumination per unit of area is dependent on the sectional area of the pencils of light from it that enter the eye, it is evident that if r_1, the radius of the eye pupil, be larger than the radius of the peep hole, the apparent brightness of the target as seen through the peep hole is to its apparent brightness when viewed by the unobstructed eye as the ratio $\frac{r^2}{r_1^2}$. Since the radius of the normal eye pupil when dilated at night is one-tenth inch, if our peep sight is to be effective at night the radius of the peep hole should be at least one-tenth inch; but with this value of r, it is impracticable to make R, the distance to the front sight, great enough to ensure sufficient accuracy. For this reason, even if there were no others, the peep sight could not be made an efficient night sight. However, in the daytime the apparent brightness of the target is of no consequence, and we can make the peep hole small enough to reduce the parallax error to a negligible quantity.

The peep sight is installed on many of our sight mounts, and was designed to be the night sight, being arranged so that the front sight point can be illuminated; but in August, 1905, after some experiments in the subject of night sights at the Naval Gun Factory, the telescope was developed to such an extent that its gain in efficiency over the peep sight for night work is something over 3000 per cent. The peep sight is therefore retained merely as a stand-by in event of injury to the telescope.

527. **The telescope sight** is the most convenient and most efficient means of establishing the sight points. It may be defined as the combination of two systems of lenses on a common axis spaced so that the second focal plane of the first system (the objective equivalent) is coincident with the first focal plane of the second system (the eye piece equivalent), which plane contains a pair of intersecting cross wires or etched cross lines.

There are three points in the telescope that determine the line of sight; namely, the intersection of the cross lines, and the first and second unit points of the objective equivalent. The stability

of the line of sight with reference to the sight mount therefore depends on the rigidity of the point of intersection of the cross lines and all optical parts in front of it.

The telescope is so attached to the gun that the line of sight can be set at any desired angle with the axis of the gun. Some confusion exists as to the nomenclature of "telescopic sights." In the case of telescopic sights the word "sight" refers to the heavy steel yoke attached to the gun slide or to the trunnion, while the word "telescope" refers to the optical instrument through which the gun pointer sees the target.

Telescope Sights.

528. There are four varieties of telescopes used as gun sights in the navy.

The first type has the *universal focus; i. e.*, has no adjustment whatever, for focusing. The first of these was of $2\frac{1}{2}$ power, and had no means for focusing the eye piece to suit individual eyes. This form is obsolete, as modern fixed-power telescopes have a means of focusing the eye piece so as to accommodate the individual eye.

The second type is the standard *variable-power telescope*. The variable power is secured by moving the eye-piece tube in and out and then clamping it at the desired power, after which the telescope is focused.

In the modern type of variable-power telescope used for turret trainers, two magnifications are obtained by moving the position of the erecting system. Distinct vision is obtained only at two powers in this type.

Another form of variable power is obtained in the continuously variable-power telescope. By means of a spiral on the inside of the telescope, the position of the erecting system is changed, and at the same time the relative positions of the lens of the erecting system themselves are changed. This gives a clear, distinct vision while changing from one power to another.

The third type is the *prismatic telescope*, which has two 90° elbows, so that an indirect line of sight is obtained. This telescope is fitted with prisms, to obtain the required change of direction.

This type was originally intended for turrets only, but is now supplied for broadside guns.

The fourth type is the *checking telescope,* which may be any of the above three types fitted with a second eye piece, so that two observers may see through the telescope at the same time. This is attained by means of a prism inserted in the path of the rays from the objective to the primary eye piece. One disadvantage of this scheme is that each observer gets only half the light that he would receive ordinarily.

As this checking eye piece is intended for use in training pointers, the latest telescopes are fitted so that the checking eye-piece system can be thrown out at will.

529. **Advantages of the telescope sight.**—The first point of superiority of the telescope as a sight is the fact that the eye is focused for any one distance, instead of successively accommodating for three, as with the open sight, or successively for two, as with the peep sight. This is because the eye, when the adjustment of the telescope is correct and the target is at long range, sees, through the eye-piece equivalent, the intersection of the lines and the image of the target in one plane. Furthermore, under the above conditions the pencils of light that emerge from the eye piece are parallel pencils, and the accommodation muscles of the normal eye are at rest when it is receiving such pencils. With the open sight and peep sight, if the eye is moved off the line of sight, errors in pointing will occur; but with the telescope, motion of the eye either across or along the line of sight will not affect the accuracy of pointing, provided the telescope is properly adjusted and the target is at long range. For as long as the eye is in some position where it will receive a part of some pencil that emerges from the eye piece after diverging from the intersection of the lines, it will see the intersection of the lines and some part of the field of view. There are limits along the axis of the eye piece and across it within which the eye should be placed if it is desired to utilize the full field of view and receive the maximum amount of light from the target; however, the rubber buffer fitted on the eye end of the telescope makes it easy for the eye to place itself within the proper limits.

The next point of superiority of the telescope is its magnifying power. At modern battle ranges it is necessary to have an apparent enlargement of the target in order to point the gun with sufficient accuracy. Where F is the focal length of the objective equivalent,

and f is the focal length of the eye piece equivalent, the magnifying power of the instrument will be $M = \frac{F}{f}$ diameters. For instance, if F be 20 inches and f be $2\frac{1}{2}$ inches, the magnifying power will be 8 diameters. When using this telescope on a target distant 8000 yards, we can lay the gun with as much facility as we could lay it on the same target distant 1000 yards with a sight that has no magnifying power. But the increase of magnifying power is attended with a corresponding decrease in the field of view. Roughly, the field of view of any telescope will be 35° divided by the magnifying power. We are therefore restricted in the application of this point of advantage by the size of field of view which is large enough to permit the gun pointer to "pick up" the target.

Another point of advantage in the telescope sight is the fact that the size of the emergent pencils does not affect the accuracy as does enlargement of the hole in the peep sight. When M is the magnifying power and A is the aperture of the telescope, the diameter of emergent pencils will be $\frac{A}{M}$. By making the proper relation between A and M we can utilize the full area of the dilated eye pupil at night; and so, instead of making it more difficult to pick up a target when looking through the sight than it is when looking with the naked eye, we can, with the new telescopes in service, pick up and lay on a target that is so dimly illuminated as to be invisible to the naked eye. But the proper relation between aperture and magnifying power is only one of several points in the design of our telescopes (some of which are confidential) that make them highly efficient night sights.

530. Parallax.—*When the image of the target and the cross lines in the telescope do not lie in the same focal plane in the instrument an error exists known as* ***Parallax.***

It is easily detected by laying the telescope on a fixed mark, keeping it in a fixed position, and then moving the eye up and down or sideways across the eye piece. If there is no apparent motion of the intersection relative to the image, they are both in the same plane; if the intersection appears to move over the image in an opposite direction to the motion of the eye, the image lies forward of the lines; if it appears to move over the image in the same direction as the motion of the eye, the image lies in rear of

the lines. The second-mentioned condition would be due to incorrect adjustment of the telescope; the third condition would be due to incorrect adjustment of the telescope; the third condition would be due to incorrect adjustment if the mark selected for the test is more than a mile distant. When a telescope has an objective equivalent of a moderate focal length like that in our telescope sights, and the telescope is in correct adjustment, the image of an object distant anywhere from infinity to a mile is not perceptibly in rear of the second focal plane of the objective equivalent—the

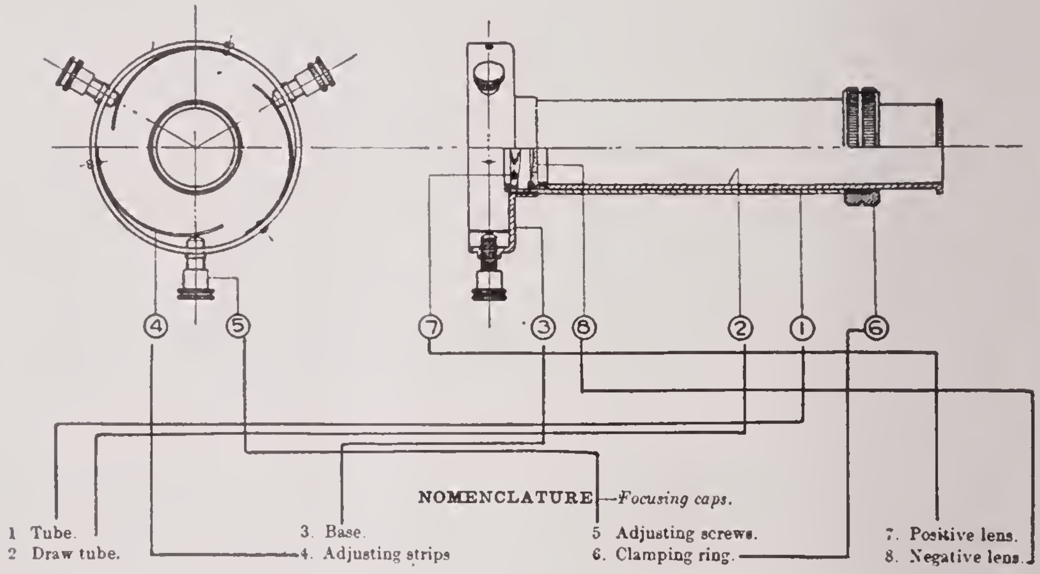


FIG. 91.

position of the cross lines. Actually, however, the image is in rear of this position a distance $Y = \frac{F^2}{X}$, where F is the focal length of the objective equivalent, and X is the distance of the object measured forward of the first principal focus of the objective equivalent. From this it is evident that, if our telescope is adjusted for long range, the image of a miniature target as close as the end of a Morris Tube boom (or in the corresponding position in a dotter), will be so far in rear of the cross lines that it will give a very large amount of parallax.

Formerly, to obviate this condition the telescope was re-focused (by increasing the distance between the cross lines and objective equivalent) to make the image of miniature target and cross lines coincident; but this is bad practice, for the reason that it involves a disturbance of the bore-sighting adjustment, which makes it necessary for the ship to go into still water, readjust the telescope for

long range, and bore sight again before the gun can be fired. We now have an optical instrument called a *focusing cap* which makes it possible to use the telescope on a near miniature target without disturbing its adjustment or the adjustment of the sight mount for long-range firing. Focusing caps consist of a *positive lens* (7) and a *negative lens* (8) so mounted that the distance between the two lenses may be varied at will. The two lenses are held at the desired distance apart by the *clamping ring* (6). By means of the three adjusting strips (4) and the adjusting screws (5) the focusing cap can be adjusted to most telescopes. Special base fittings are required with the latest marks of telescope, but in such cases the special bases are furnished with the caps. (Fig. 91.)

In using, the telescope itself should be focused on a distant object until free from parallax. The focusing cap is then shipped in place on the objective end of the telescope, the telescope is directed toward the dotter target, and the draw tube (2) is moved in and out until the image of the target is clear and distinct and the cross lines are sharp and without parallax.

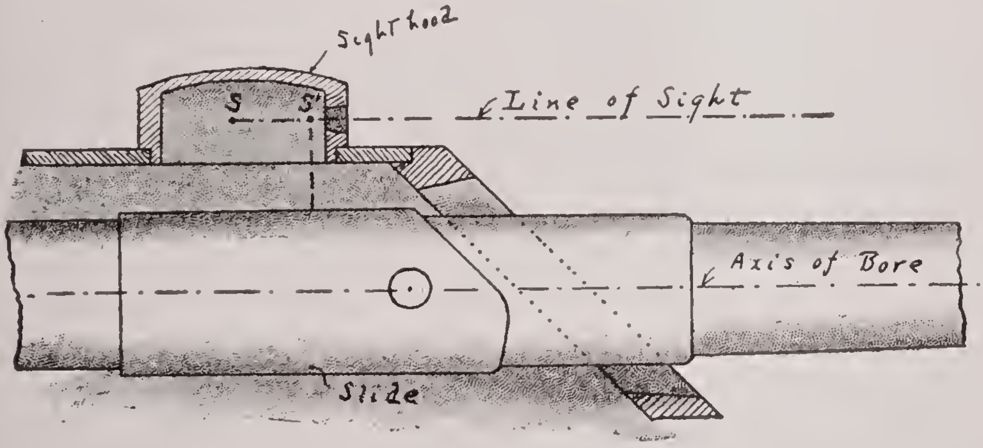


FIG. 92.

531. Parallel-motion sight mounts.—When the opening for the line of sight is in a *hood* on the roof of a turret, it is impracticable to attach the sight mount directly to the slide; the pivot bar is so far from the trunnions that elevation of the gun causes it to move to the rear and downward a considerable distance. This condition is illustrated by Figs. 92 and 93, which show, respectively, the relative position of gun and line of sight when the gun is level and when it is elevated. In Fig. 93 it will be seen that the line of sight is below the opening in the hood, although the gun is not at extreme elevation.

532. Roof sight mounts are therefore indirectly attached to the slide by a parallel-motion mechanism; the *pivot bar* with the fittings for its horizontal and vertical axes, the *sight bar,* and *sight-bar bracket* are mounted on an arm, called the *connecting arm,* that has a horizontal axis at its upper end in a fixed position with

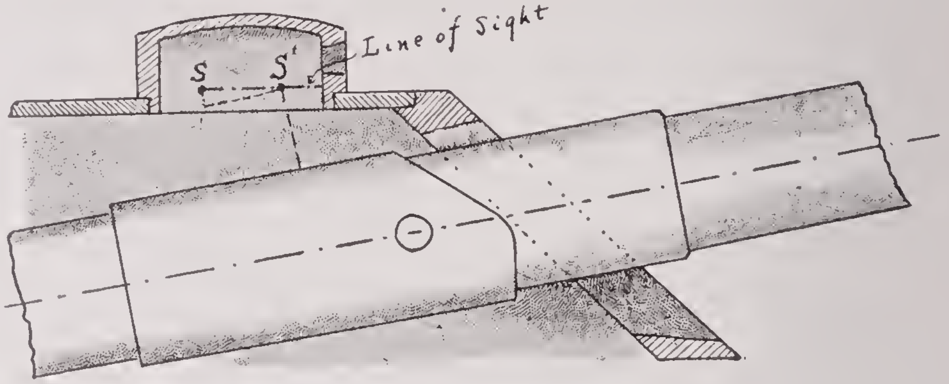


FIG. 93.

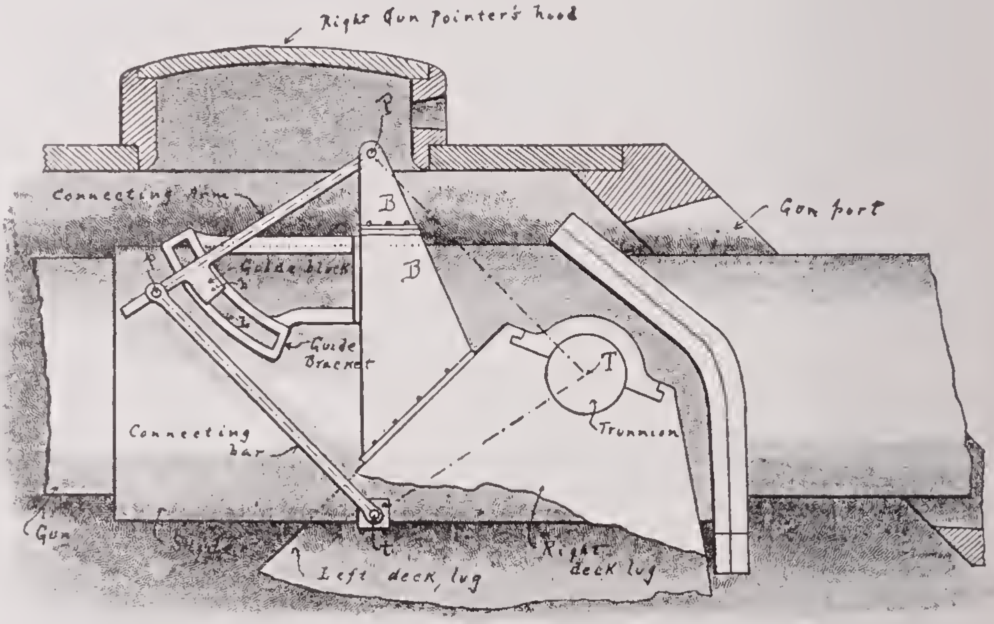


FIG. 94.

reference to the deck lug, and is connected to the slide so that it will move in elevation with an angular motion exactly equal to the angular motion of the gun in elevation. One method of imparting this motion to the connecting arm is shown in Fig. 94.

In Fig. 94 the connecting arm *pP* has its fixed axis at *P* in the sight bracket *B*, which is made up of two parts bolted to the deck

lug. At its rear end it engages the bar pt, called the *connecting bar,* on the shaft bolt p; this in turn is connected to the slide on the shaft bolt t. In the parallelogram $PpTt$, the side PT = side pt, and side pP = side Tt; P and T are fixed points of the parallel motion, T being the axis of trunnions of the gun. A *guide block b,* which is a part of the connecting arm, works in the circular slot L, in the *guide bracket,* machined to arcs of circles centered in the axis P. The guide bracket is bolted to the lower part of the *sight bracket;* with the guide block, it prevents lateral bending of the connecting arm. The connecting arm will work through angles exactly equal to angles described by the axis of the bore of the gun only when the following conditions are maintained:

(a) That the axes P, p, and t are installed exactly parallel to the axis of the trunnions.

(b) That the distance from the axis P to the axis p is exactly equal to the distance from the axis t to the axis of the trunnions T; also that the distance from the axis p to the axis t is exactly equal to the distance from the axis P to the axis of the trunnions T.

Although the parallel motion may have been installed in conformity with the above conditions, it is evident that any bending or springing of the connecting arm or the connecting bar will distort the parallelogram and cause pointing errors that may be either vertical or horizontal. A material looseness caused by wear in the working surfaces will result in vertical errors in pointing. Any change of the position of the trunnions with reference to the deck-lug will also distort the parallelogram. When the gun is being elevated, the slide tends to shift forward in the deck lugs; so, if there is too much clearance in the trunnion seats, the axis of trunnions will shift forward far enough to make a material error in the parallelogram. Upon depressing the gun, the shift is in the opposite direction. Naturally, any adjustment of the frictionless trunnions that is different from the adjustment at the time the parallel motion was installed will affect the parallelogram.

533. Another form of parallel motion is shown in Fig. 95. The connecting bar pt and shaft bolt t of Fig. 94 are replaced by the circular *cam C* that is bolted to the slide; the center of curvature of this cam is at a point t which is in a fixed position with reference to the slide and axis of trunnions, such that $tT = pP$ and $tp = TP$.

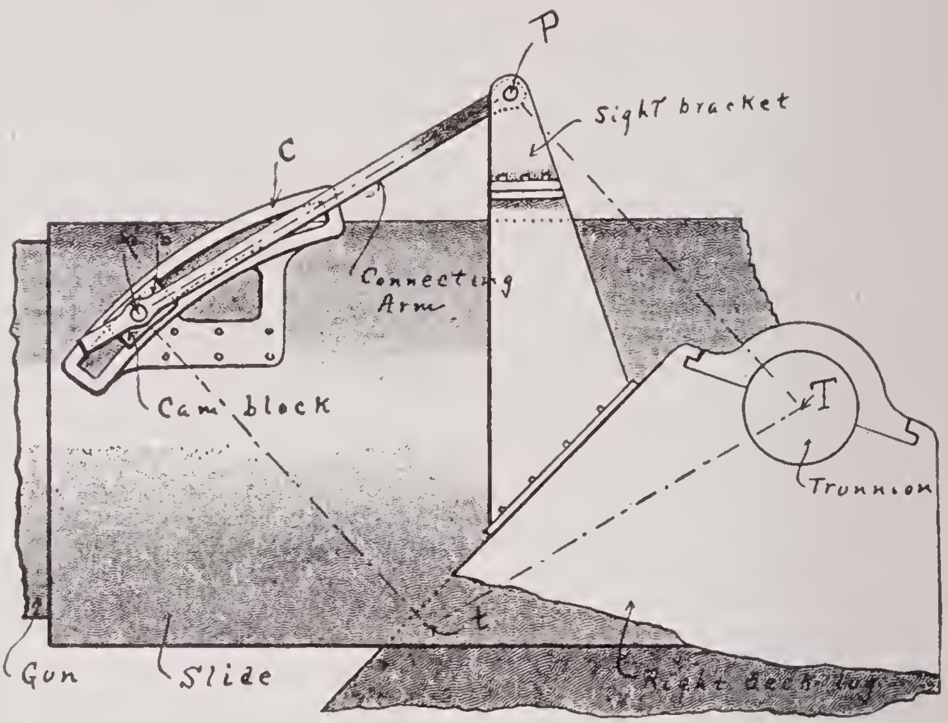

P
Sight bracket
C
Connecting Arm
Cam block
T
Trunnion
t
Gun
Slide

Fig. 95.

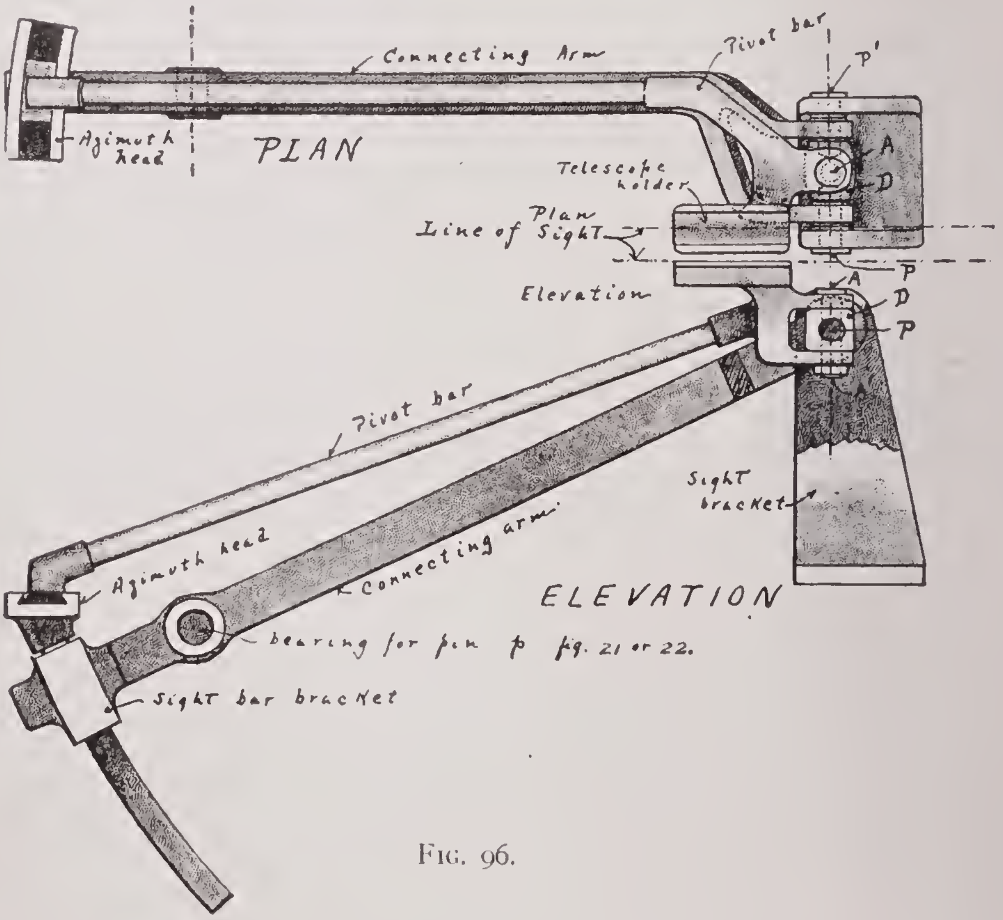

Connecting Arm
Pivot bar
P'
Azimuth head
PLAN
A
D
Telescope holder
Plan Line of Sight
Elevation
P
A
D
P
Pivot bar
Sight bracket
Azimuth head
Connecting arm
ELEVATION
bearing for pin p fig. 21 or 22.
Sight bar bracket

Fig. 96.

The rear end of the connecting arm contains a shaft bolt p set up in the *cam block b*. The flat face of the cam must be installed exactly in a plane perpendicular to the axis of trunnions. The parallelogram then is $PpTt$, as in the preceding figure.

The advantages of this form of parallel motion are: No matter how long the connecting arm may be, the cam prevents its rear end from being sprung laterally; and, as there are fewer working parts, there are fewer errors due to wear in bearing surfaces.

534. A method of mounting the pivot bar, sight bar and sight bar bracket on the connecting arm is shown in Fig. 96. It will be seen that the *horizontal sight axis* PP' is coincident with the upper axis of the connecting arm. It is formed by the two trunnion bolts P and P' tapped into the jaws of the bracket; these are the bearings for the jaws of the connecting arm and for D, the *pivot-bar block*, into which is tapped the bolt A that forms the *vertical sight axis* AA'. The sight-bar bracket is bolted to the connecting arm at its rear end.

535. Tests of parallel-motion mechanism.—For tests of parallel motion mechanism, two observers are required—one to look along the axis of bore, the other to look along the line of sight.

First inspect for lost motion as follows: Direct the axis of bore to a distant mark by motion of the gun, and direct the line of sight to the same mark by motion of the pivot bar. Move the gun to extreme elevation, and then depress it until the observer at the breech notes the axis of bore on the distant mark. Then move the gun to extreme depression and elevate until the observer at the breech notes the axis of bore again on the mark. Each time the observer at the breech is exactly on, the observer at the sight should also be exactly on. Lost motion may appear as follows: Both may be on when the axis of bore has been elevated to the mark, but the line of sight will point high after the gun has been depressed to the mark; or else both may be on when the axis of bore has been depressed to the mark, but the line of sight will point low after the gun has been elevated to the mark. The error may be due to any of the following conditions:

(a) Looseness in the bearings of the parallel motion.

(b) Bending of either the connecting arm or connecting bar, caused by very tight bearings.

(c) Shifting backward and forward of the axis of trunnions, caused by too great clearance in the trunnion seats.

After the parallel motion has passed a thorough test for lost motion, it should be tested for accuracy of the parallelogram as follows: Elevate the gun until the axis of bore is directed to the center of a heavenly body in the west, selecting a time that will give extreme elevation to the gun. Simultaneously, by motion of the pivot bar, bring the line of sight to the center of the same body. When the body is near the horizon, lay the axis of bore on its center; now, if the line of sight is also on, we can be satisfied that the parallelogram is properly proportioned and that the upper axis of the connecting arm is parallel to the axis of the trunnions.

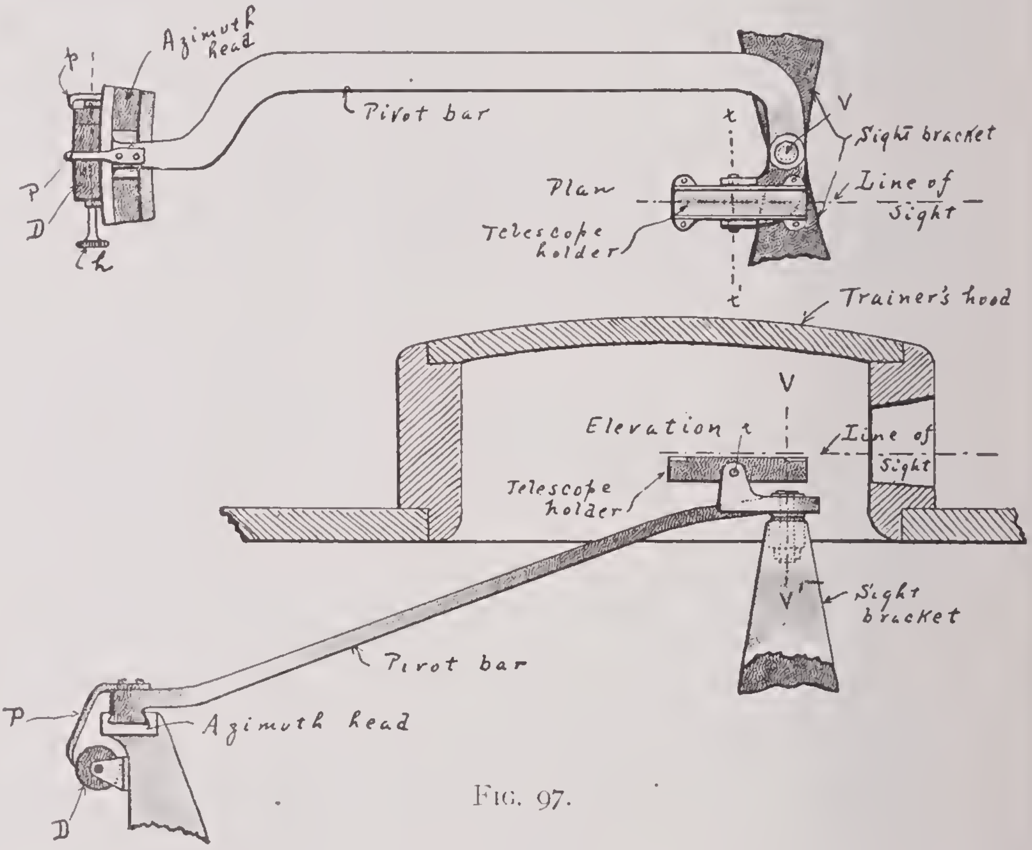


FIG. 97.

If the parallelogram is not properly proportioned. the line of sight will be high or low when the axis of bore is on; if the upper axis of the connecting arm is not parallel to the axis of the trunnions, the line of sight will point to the right or left when the axis of bore is on. It is obvious that, before making this test, we should see that the frictionless trunnions are correctly adjusted to the positions they are to be in during firing.

536. Turret trainer's sight mount.—The trainer's sight mount in turrets is usually placed between the two guns. It is not connected to either gun slide but has two parts that are in a fixed posi-

tion relative to the two pairs of deck lugs. In Fig. 97 these fixed parts are the *sight bracket* and the *azimuth head.*

The pivot bar is capable of motion in azimuth about the vertical sight axis vv'. This axis must be installed exactly perpendicular to the plane of the roller path of the turret. The rear end of the pivot bar travels in the circular slot in the azimuth head and carries the pointer P for indicating the setting in azimuth. It will be seen that the pivot bar has no vertical motion; therefore, in order that the trainer may keep the target within the field of view of his telescope while the ship is rolling, the *telescope holder* has a

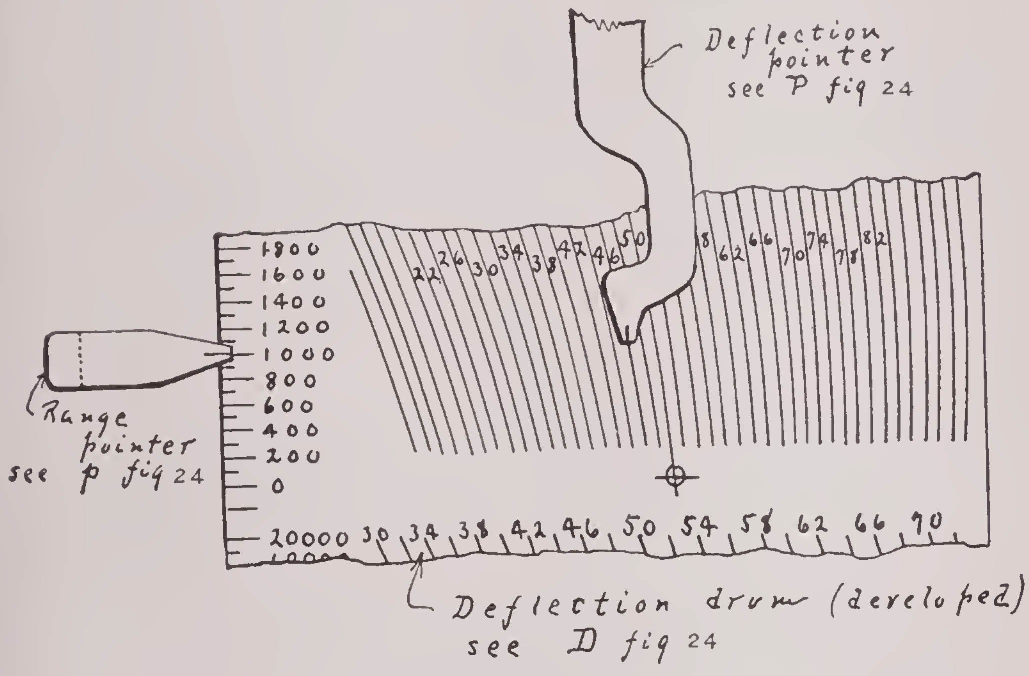


FIG. 98.

trunnion mounting on the pivot bar. The axis of this trunnion mounting, tt', must be installed exactly at right angles with the vertical axis vv'. The azimuth scale is engraved on the *deflection drum D,* of which a development is shown in Fig. 98; the graduations on this drum are determined from the graduations on the azimuth plate on the pointer's sight. In order that the azimuth changes of the trainer's line of sight shall equal the azimuth changes of either pointer's line of sight, the drum must be rotated by the handle h until the reading by the scale and small reference pointer p on the end is opposite the range reading set on the pointer's sight; then, when the pivot bar is moved to the left or right until the reference mark on the pointer P touches the speed-

line that has the same number as the speed line to which the pointer's sight is set, the azimuth change from the bore sighting position will be the same in each sight.

537. **Adjustment of trainer's sight.**—Turret guns are required to be installed so that the axes of the bores are parallel or converge slightly. In bore sighting all three sights, if the firing is to be at long range, the position of the trainer's line of sight should be midway between the pointers' lines of sight when all scales read zero; this, of course, puts both pointers a little bit off laterally

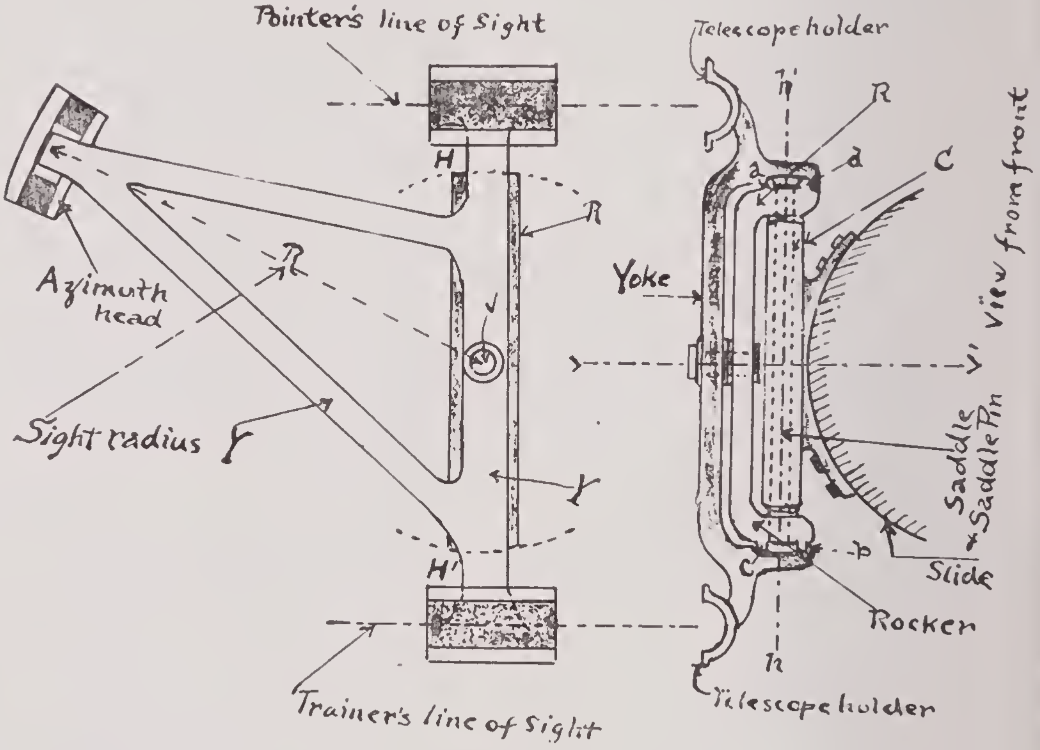


FIG. 99.

when the trainer is on. At short-range firing, where this discrepancy will amount to a considerable portion of the area of the target, the trainer should lay his line of sight a certain amount to the right of the bull's-eye when the left gun is to fire, or a certain amount to the left when the right gun is to fire, the amount he is to aim off the bull's-eye being half the divergence between the two pointers' lines of sight.

538. **Yoke sight mounts.**—The two lines of sight, one for the pointer and one for the trainer, with guns not mounted in turrets, are now carried on one sight mount which is a modification of the

type shown in Plate I. This modification, which is called the *yoke mount,* is illustrated by Fig. 99.

Instead of a pivot bar we have a *yoke Y* which amounts to a pivot bar spread out wide enough to carry a telescope on each side of the gun. The rear end of the yoke works in the azimuth head on the sight bar in the same manner as the rear end of the

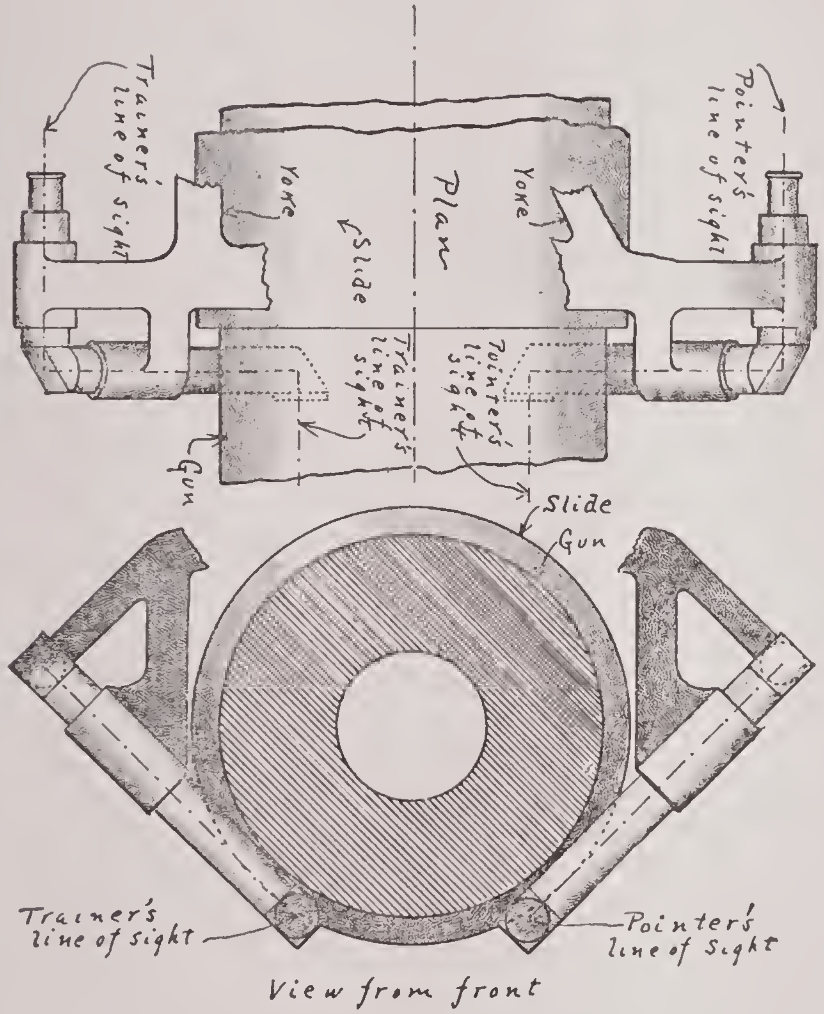


FIG. 100.

pivot bar in Plate I. The horizontal sight axis is formed by a shaft hh', called the *saddle pin,* in a casting C called the *saddle,* and engaging a casting R called the *rocker.* The vertical sight axis is formed by the pin vv' which centers the yoke in the rocker. The upper and lower side edges of the rocker, a, b, c, d, are machined to arcs of circles centered in vv' to a working fit in the yoke; this gives stiffness at the positions H and H' where the

castings called *telescope holders* are connected to the yoke. The left-hand telescope holder carries the pointer's telescope; in bore sighting, this line of sight is adjusted to the axis of bore by motion of the yoke in the azimuth head and by motion of the sight bar. The right-hand telescope holder carries the trainer's telescope, and is adjustable with reference to the yoke, so that this line of sight can be directed to the point of intersection of the axis of bore and the pointer's line of sight; the mechanism of this adjustment is not shown in the figure. The sight bar, and sight-bar bracket, are the same in principle as those in Plate I.

539. Periscopic sights for broadside guns.—With the sight mount shown in Fig. 99, the wide distance between the two lines of sight makes the opening in the gun shield very large. Besides this, the effective arc of train of the gun is considerably less than the actual arc that the gun covers in moving from one edge of the port to the other; the pointer's line of sight will be masked when the gun is at extreme train left, and the trainer's line of sight will be masked when the gun is at extreme train right. These two faults are corrected by using *prism telescopes* in which the line of sight, in effect, is turned through two right angles, as shown in Fig. 100. The sight mount for these telescopes is practically the same as the mount shown in Fig. 99, so it will be sufficient in Fig. 100 to show a portion of the yoke, with the telescope holders, and the positions of telescopes relatively to the gun when the sight bar is set at zero. (See also Chapter X, Plate II, Fig. 1.)

540. Periscopic sights for turret guns.—Troubles with the adjustment and difficulties with the installation of parallel-motion sight mounts have led to the design of a prism telescope in which the line of sight is, in effect, turned through two right angles. This telescope is placed so that it projects through a hole in the side of the turret in line with the axis of the trunnions of the gun, as shown in Fig. 100. It is carried in a sight mount similar in principle to the mount shown in Plate I; being attached directly to the slide and trunnion, it has no parallel-motion mechanism.

The fixed parts of the sight mount are the sight-bar bracket *B*, bolted to the slide and trunnion, and the sight bracket *S*, bolted to the slide. The pivot block engages the shaft pin *vv'*, which journals in the sight-bar bracket, and forms the vertical sight axis. The pivot bar is machined to bearings on the top and bottom of

the pivot block in order to give lateral stiffness to the support for the telescope holder; it also engages the pin *hh'* which is tapped into the rocker and forms the horizontal sight axis. The two sight axes intersect at right angles. The rear end of the pivot bar works laterally in a slot in the azimuth head, which, with the sight bar and sight-bar bracket, is practically the same as in Plate I. On

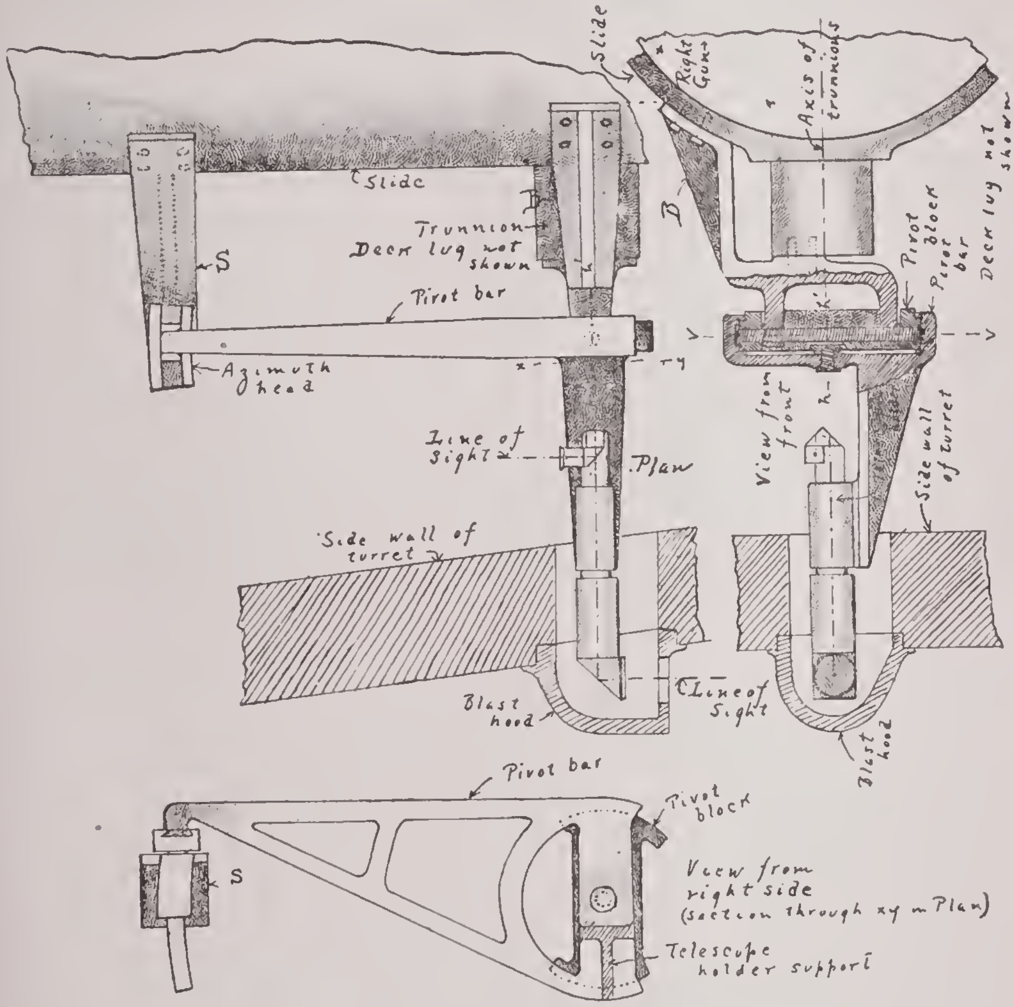


FIG. 101.

account of the flatness of the trajectory of the gun with which this sight is used, the range and deflection scales are of the multiplying type. The directions of the line of sight at the objective end and eye-piece end of the telescope are shown in dot-and-dash lines on the plan. The outer end of the hole in the side wall of the turret is partly covered by a small hood called the *blast hood*.

541. The trainer's telescope in turrets fitted with periscopic sights is of the same design as the pointers' telescopes, but is mounted vertically instead of horizontally. The opening for it, in the turret armor, is in the front face of the turret between the guns

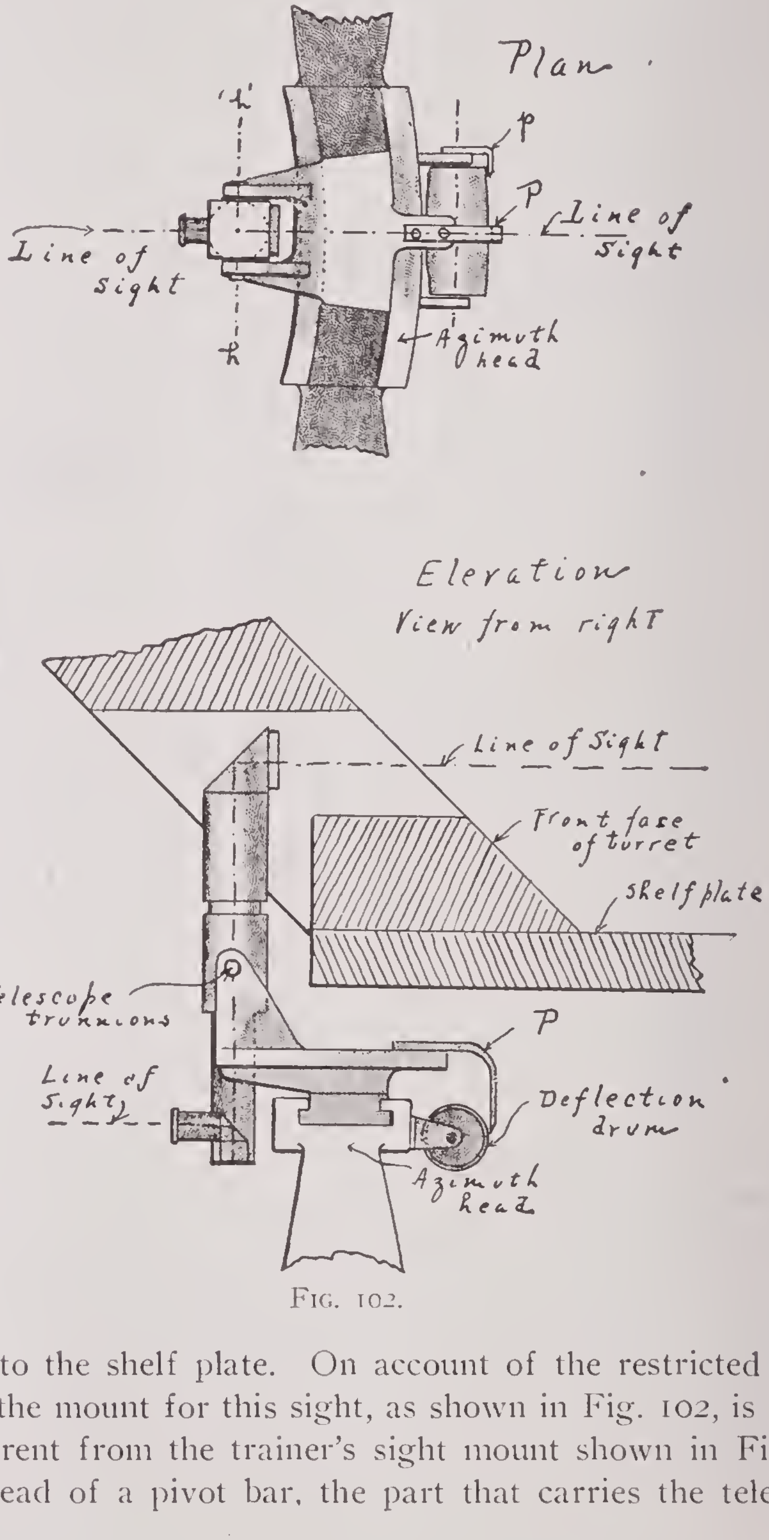


FIG. 102.

and close to the shelf plate. On account of the restricted space available, the mount for this sight, as shown in Fig. 102, is somewhat different from the trainer's sight mount shown in Fig. 97. Here, instead of a pivot bar, the part that carries the telescope

trunnions moves in a slot in the azimuth head which is machined to the arc of a circle that has a virtual center corresponding to the vertical axis of the pivot bar in Fig. 97. The deflection drum and pointers are practically the same as in Fig. 97, but the sight-setter's position is in front instead of in rear of the trainer.

542. Latest turret sights.—On the latest turret guns a yoke sight is installed, but instead of being pivoted to the top of the slide it is pivoted underneath. It is fitted with a prism telescope. The line of sight from the objective end of the telescope is underneath the guns. The guns are fitted with shields which give the protection made necessary by the larger port openings in the front face plate of the turret.

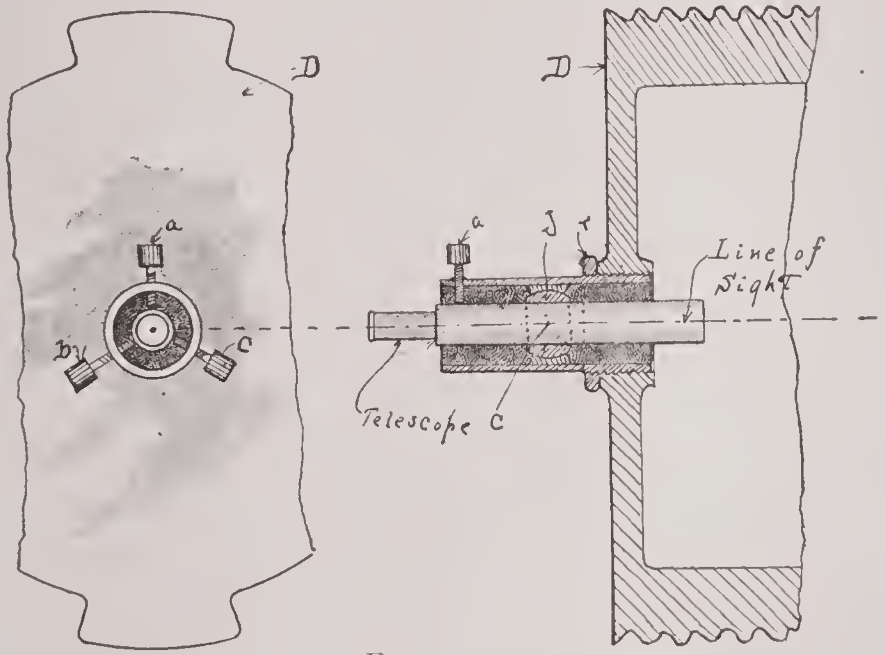


FIG. 103.

543. A bore sight is a telescope sight mounted as shown in Fig. 103. The telescope holder *H* screws into a threaded hole in the center of the casting *D,* called the *breech disk,* which is machined to fit into the screw box of the gun with which the bore-sight telescope is to be used. The telescope is mounted in its holder by a ball-and-socket joint *J*—the center of the ball, *c*, being in the axis of the holder and the geometrical axis of the telescope. The specifications for the telescope require its line of sight to be coincident with its geometrical axis; thus *c,* the center of the ball-and-socket, lies in the line of sight. The telescope is adjustable about *c* as a center of motion by means of the three thumb screws *a, b,* and *c.*

There is an accessory of the bore sight called the *muzzle disk.* This consists of a circular casting machined to fit snugly in the muzzle of the gun with which the bore-sight telescope is to be used. It contains a central hole that is $\frac{1}{16}$ inch in diameter, if the disk is for heavy guns, but is smaller in the disks for short guns.

544. **The object of bore sighting** is to bring the lines of sights through the pointers' telescopes to intersect the axis of the bore extended, at the mean range at which it is expected to fire; so that with the gun properly bore sighted and with the sights correctly set, an accurately aimed shot will hit the "point of aim." Of course, at ranges shorter than that at which bore sighted, the lines of sights will intersect behind the target and at longer ranges, in front of the target.

The target used in bore sighting is a specially prepared screen, on which are painted vertical and horizontal lines; the screen is properly mounted in a boat and the boat anchored at the desired range; this range being the mean range at which it is expected to fire. It sometimes happens that suitable objects are available, such as prominent marks on shore, beacons, etc., in which case in order to save time, the regular target would not be sent out. For long range bore sighting, it is customary to anchor the ship at the desired range from some land mark or other prominent object, and not use the target.

545. **To bore-sight a broadside gun,** we proceed as follows:

(1) Preliminary to the bore sighting proper, the pointer's and trainer's telescopes should be examined, cleaned if necessary, focused, and all parallax removed. The telescope holders should be clean, and telescopes mounted securely in the brackets. The sight mount should be clean, work easily, and have no lost motion. Set sights so the scales read zero range and 50 deflection.

(2) Open the breech plug of the gun and lash it open, so as to prevent its swinging part way shut and injuring the bore sight.

(3) Ship the breech disk (breech adapter) in the screw box and clamp it rigidly in proper position as indicated by square marks on breech and disk.

(4) Enter the telescope holder in the threaded hole in the breech disk, screw home, and then set up tight on the locking ring *r*.

(5) Focus the telescope for distinct vision on an object distant not much less than one mile, by moving the eye-piece tube in or out. Test for parallax. There should be no parallax, since the cross lines of this telescope are permanently fixed in the second focal plane of the objective. If, however, parallax does exist, another telescope must be used, or the parallax must be removed by sacrificing some of the focus. In some cases, it will be necessary to place a piece of paper over the eye piece and punch a pin hole through the paper, in order to overcome the effect of the parallax, and at the same time secure distinct vision.

(6) Ship muzzle disk; see that the lip or a line on its periphery touches the muzzle face all around.

(7) By movement of the thumb screws *a, b* and *c* (there are four of these thumb screws on all of the latest Marks), direct the line of sight of the telescope to the hole in the muzzle disk. Since this hole is comparatively close, its image will lie in rear of the cross lines and will appear as an indistinct, rather large, round bright spot. We would have considerable parallax between the cross lines and this image if it were not for the fact that the brass cover on the eye end of the telescope has only a small opening, and therefore the eye cannot move much off the axis of the telescope without losing sight of the image. When the intersection of the cross lines appears to lie in the center of the image, see that the three (four) thumb screws are set up tight. On a cloudy day, there may not be enough light through the hole in the muzzle disk to make the cross lines visible. In this event the lines can be seen by means of a portable electric light hung inside the breech disk, a little to one side of the telescope.

(8) Test the adjustment of the bore sight by rotating the muzzle disk through 180°; if this makes no difference in the apparent position of the intersection of the cross lines on the image, it is evident we have placed the line of sight coincident with the axis of the bore.

(9) Remove muzzle disk.

(10) Man stations at telescopes, officers at trainer's telescope. Pointer coaches trainer crying "Mark" when vertical wire is on; the officer notes the error of trainer's vertical wire and by means of the adjusting screws on the trainer's telescope, brings the trainer's vertical wire on with the pointer's. The procedure is repeated for the trainer's horizontal wire, it being brought on with

the pointer's by means of another set of adjusting screws on the trainer's telescope. The pointer's and trainer's cross lines are now together.

(11) Officer now mans bore sight, pointer and trainer at regular stations. The officer coaches pointer and trainer, officer and pointer crying "Mark" when vertical wires are on. By means of the sight-setting mechanism, set the sights over in deflection until pointer is on with bore sight. This should of course bring the trainer on with the bore sight at the same time. Check trainer's vertical wire with bore sight vertical wire. The procedure is repeated for the horizontal wire, it being brought on with the horizontal of the bore sight by setting the sights in range. Both the pointer's and trainer's cross lines should now check with the cross lines of the bore sight.

(12) When the officer is satisfied that all three sights are together, unclamp the range and deflection scales and shift them to 0 range and 50 deflection and clamp tight. Care must be taken in shifting the scales, that the scales, only, are shifted, and that the sights themselves are not moved.

(13) Check sights with bore sight to see if sights were moved; if satisfied as to the bore sighting, shift stations, the officer checking both telescopes. This is important, not only that the officer may check the pointers, and so serve to eliminate error, but also that the pointers may be assured that the telescopes are truly "on" with the bore sight and hence, any misses in firing cannot be laid to poor bore sighting.

(14) Run the sights up and down; right and left. Set again at 0 and 50; and check again at all stations.

(15) Put muzzle disk in again and see if the bore-sight line of sight is still coincident with the axis of the bore.

(16) Report to the gunnery officer that the gun is bore sighted and ready for inspection.

(17) After inspection hang a large placard on the gun announcing "Hands Off—Bore Sighted," or similar warning, move to next gun, or stow gear.

In the case of the latest periscopic sights, the cross-line lenses are made movable, so that step (10) as given above is accomplished by moving the cross lines themselves. Step (11) also, may be accomplished in the same way with this type of sight, or as stated under (11).

546. To bore-sight a turret, the procedure is the same, so far as regards the pointers' sights, as for a broadside gun; that is, each pointer is put on with his respective bore sight. The trainer, however, must be placed midway between the guns in case of a two-gun turret, and with the middle gun in the case of a three-gun turret.

The details of bringing the cross lines "on," shifting the scales, etc., are not given since they vary somewhat with each type of turret; the principle, however, is the same in all cases and if, this principle and the object of bore sighting are clearly understood, the details will present no serious difficulties.

Notes on Care and Handling of Telescopes.

547. General directions.—Telescopes should never be dismounted unless it is absolutely necessary, and then only by an officer or other person skilled in such work.

As optical parts of a telescope are not interchangeable, one telescope should be completely reassembled before starting to disassemble another. A line scratched across a joint between two parts of a telescope before disassembling, will facilitate reassembling.

The objective lens is provided with a cover, and it should be kept in place at all times when the telescope is not in use; otherwise the sun will cause the balsam cement to crystallize.

When possible, telescopes should be stowed in a warm, dry place, in boxes provided for them.

Telescopes should be cleaned with a dry cloth (nothing else), and the cloth should never touch the lenses.

Special care should be taken to prevent injury to pentagonal bearings, especially the two lower faces.

All telescopes are marked "up" on the side which should be uppermost when shipped.

Care should be taken that the telescope holders are kept clean and smooth. Emery, etc., should never be used for cleaning them.

Whenever possible, a gun should be bore sighted after shipping a telescope. While such telescopes as have non-adjustable cross lines have been carefully inspected to see that the cross line, intersection of all telescopes coincides for a distant object, bore sighting should always be resorted to if possible after changing a telescope in the telescope holder.

Care must be taken that the screw heads of the telescopes are not allowed to become rusted. In all future telescopes, these exposed parts will be made of Monel metal. Frequent examination of these should be made to see that they are not slacked back.

Do not tamper with the bolts which are used to fasten together the flanges of the various parts of a prismatic telescope. This adjusting can only be done by an experienced man, and requires tools not to be had aboard ship.

548. Cleaning lenses.—Lenses should be wiped off only when necessary, for cleaning destroys the polish, thereby diminishing the amount of light passing through. If they are very greasy, a few drops of alcohol applied with a brush and then wiped with clean chamois skin will usually be sufficient. Handle lenses by the edges. Dust can be removed by means of a dry camel's-hair brush.

Each pointer and trainer should have at hand a piece of chamois selvyt, or lens paper, so that he may be able to wipe off the eyepiece lens in case it becomes covered with moisture, as it does sometimes. In no case use waste. A few small holes punched in the rubber eye guard will tend to correct this trouble.

In cleaning the objective lens of a telescope when in place, special attention must be given that the objective lens does not rotate, as this will cause large errors in the line of collimation.

Compound lenses are usually cemented together with Canadian balsam, which is soluble in alcohol; hence care must be taken that too much alcohol is not used in cleaning.

The above remarks apply to the polished surfaces of prisms as well as of lenses.

In looking through a telescope, it is well to remember that all dirt that may be seen very clearly defined must lie in or very near to a focal plane. For this reason dirt on the cross-line lens is clear and distinct, while that on the objective and eye-piece lens will appear as a blur. However, dirt on any lens lessens the amount of light that is transmitted to the eye.

In cleaning cross-line lenses, do not use alcohol, as it removes the filling-in material of the etched line.

549. Adjusting the illuminator.—The illuminator, when in correct adjustment, should render visible only the intersection of the cross lines, and not the entire cross line. If the beam of light

should get off the intersection, it can be adjusted by means of the four set screws at the top of the illuminator, on the outside of the telescope. Keep caps on illuminators when not in use.

550. Focusing.—The older type of variable-power telescope (Mark X) is focused by sliding the inner tube in or out (after adjusting the outer tube for desired power) until there is no parallax. This position of no parallax marks the position of accurate focus. Once focused at, say, 2000 yards, the telescope requires no further adjustment for any distance for which it is to be used by the same observer. A knurled ring or a lever attachment is provided on later types of variable-power telescopes for shifting from one power to the other, while the focusing is done by means of the eye piece. In *all* fixed-power telescopes the focusing is accomplished by means of the eye piece.

551. Ray filters.—The ray filters accompanying telescopes are to be inserted inside the rubber buffer, close up to the eye lens. In some new telescopes, ray filters are included in the telescope itself. The dark smoked one is for night use against searchlights, while the amber colored one is for day use.

Alignment of Guns and Sights.

552. With a ship on an even keel all guns should elevate and depress in a truly vertical plane. Also the sights when run up and down independent of the guns should move in a vertical plane.

Since the installation of the gun and sight mechanisms may be imperfect, or, having been accurate, may have become deranged through use, it is necessary to check the installation to find and correct such derangement of the *alignment of guns and sights.*

Bore sighting is of no value if the alignment is out, for, with a gun perfectly bore sighted with gun and sight horizontal, if the gun elevates in one plane and the sight in another, the planes not being parallel, it is obvious that an error will appear, small at short ranges, and increasing rapidly with the range.

553. In measuring for parallelism of guns, measurements are to be taken with the guns resting in the trunnion seats, not raised on the knife edges, and, if measurements are taken by trams, they should be taken at both breech and muzzle with guns at level and at successive angles of elevation and depression by increments of about 5°.

In testing the parallelism of turret guns and sights it is convenient to consider three planes of reference, each of which is perpendicular to the other two:

1. The plane containing the axes of the guns when level. This plane should contain also the axes of the trunnions, and may, for convenience, be called the *horizontal plane.*

2. A plane through the axes of the trunnions perpendicular to the *horizontal plane.* This, for convenience, may be called the *lateral plane.*

3. A plane through the center line of the turret perpendicular to both the lateral and horizontal planes. This plane will be called the *longitudinal plane.*

It will be noted that these planes are not, strictly speaking, horizontal and vertical unless the ship is on an even keel.

It is assumed that the turret structure is properly built, the plane of the roller path being perpendicular to the longitudinal plane through the keel and center line of the ship, and the plane containing the axes of the guns when level being parallel to the plane of the roller path at all positions in revolution of the turret.

554. The traces of the longitudinal and horizontal planes are projected on a skeleton screen of smooth wide battens secured to cross-pieces, placed at a convenient distance from the muzzle of the guns; to contain the field of view through the bore sights and gun sights, from extreme depression to extreme elevation. (See Fig. 104.) This screen must be placed parallel to the "lateral plane" (*i. e.,* vertical), and held securely. The frame holding the battens is made heavy enough to permit men to climb upon it to plot points.

The trace of the vertical plane will be the line *A-B,* and of the horizontal plane will be *C-D* (Fig. 104).

555. These lines may be called the vertical and horizontal base lines, respectively.

The conditions for perfect alignment and parallelism of the axes of guns are as follows:

(a) Trunnion seats in deck lugs cylindrical and with axes coincident and perpendicular to the longitudinal center line of the deck lug.

(b) Trunnions of slides cylindrical and with axes coincident and perpendicular to the axis of the bore of the slide.

(c) Each deck lug with its longitudinal axis parallel to the longitudinal axis of the turret.

(d) The two deck lugs in one turret so set that the axes of the two pairs of trunnion seats are coincident and lie in the lateral and horizontal reference planes.

(e) The two deck lugs in a turret so set that the axes of the two guns are equidistant from the longitudinal center line of the turret. If all of these conditions are fulfilled and the guns are made to revolve about the axes of the trunnions, as in elevating and depressing, the planes in which the axes of the guns move will be parallel to the vertical reference plane and will intersect the plane of the screen in the lines *E-F* and *G-H*, parallel to *A-B* (Fig. 104) and equidistant from it.

In the middle of the flush battens are scribed right lines, as shown. These lines should be black upon a white ground and should only be sufficiently heavy to be seen through the telescope of the bore sight. The distances between the lines *E-F* and *A-B* and between *G-H* and *A-B* are equal to the distance between the center line of gun and center line of turret, as shown on the drawings, and are laid off on the line *C-D* before the vertical lines are drawn. Care should be taken to have the lines on the vertical battens at right angles to that on the horizontal batten *C-D*.

556. The guns are carefully leveled by means of trams,* and the battens, secured together, are raised until the line *C-D* comes on the horizontal wire of the bore sight of each gun, and the lines

* The line C-D represents the horizontal base line, and A-B the vertical base line. This is on the assumption that the plane containing the axes of the guns when level is the horizontal plane. In fact, the axes of the guns when level establish the horizontal plane which is really the fundamental plane from which all comparisons are made.

At shipyards the deck lugs are usually lined up with a mandrel. The height of both ends of the axis of the mandrel is measured above the roller path by means of a tram. This establishes the axis of the mandrel parallel to the plane of the roller path within the limit of accuracy expected of mechanical measurements. The deck lugs are then lined up with the trunnion seats to the mandrel. After the guns are mounted their level position is determined by mechanical measurements above the roller path and tram marks made near the breeches of the guns on the central girders. This establishes the plane of the axes of the guns when level, and when once determined as accurately as possible this plane must be the one with which all others must be compared in order to give the best results from a gunnery point of view.

E-F and *G-H* coincide with the vertical wires of the bore sights. The battens are then secured.

By means of the bore sight, the axes of the bores of the guns are projected upon the screen at successive elevations until the height of the screen is reached. Then the guns are brought to extreme depression, checking the points of projection previously obtained in elevation and at level, and another projection is marked at extreme depression. The guns are brought back to level and the point of projection in that position checked again in order

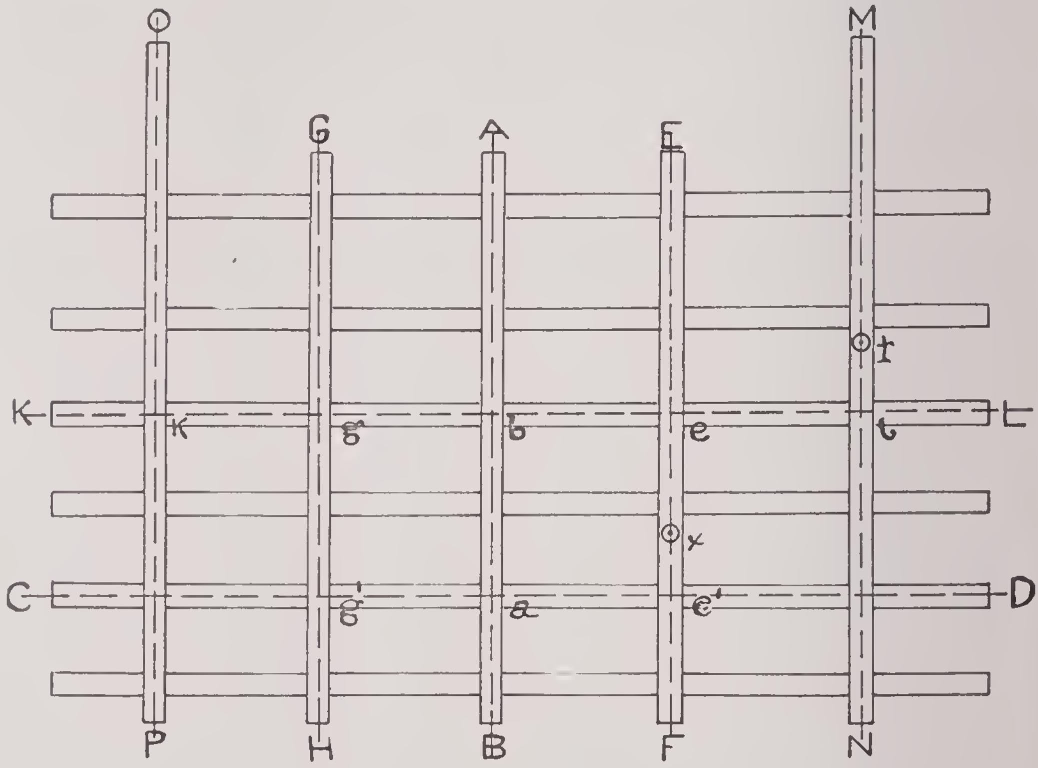


FIG. 104.

to ascertain if anything has moved. After the points have been marked on the screen the guns may be rapidly run up and down a number of times with the elevating gear for verification. A line connecting all points of projection on the screen is the "elevation line" and should be a straight line. This line may be actually drawn or not, as desired.

The elevation lines of any pair of turret guns, compared with the vertical lines and the horizontal base line (*C-D*) of the screen, will indicate the degree of accuracy of the installation, and will enable one to measure with a fair degree of precision the error,

if any exists. All that is necessary is to measure the lateral distance of the points of projection from the vertical lines. If each measurement is the same it is evident that the elevation line is on or parallel to the vertical base line; otherwise an inclination is shown, and must be corrected before the gun will fire accurately.

557. To check the motion of the sights the battens *K-L, M-N, O-P*, and *A-B* are used. These battens have right lines in the center, and are secured so that *K-L* is parallel to *C-D*, and at a height above it (in some cases below) equal to the vertical distance between the center of the trunnions and the axes of the sights. The vertical battens are secured perpendicular to the base line *C-D* and at the horizontal distances of the telescopes from the center lines of the guns. These measurements can be obtained from the drawings.

(1) **The trainer's sight.**—In a perfect installation of guns and sights this sight, when set at zero, should project its axis upon the screen at the point *b*, the point of intersection of the line *A-B* with the line *K-L*, and when elevated and depressed this point of projection should follow the line *A-B*.

To test installation of trainer's sight: Obtain the "elevation line" in the same manner as for a gun. Mark a "zero point" on this line at a height above *C-D* equal to the vertical distance between the line joining the axes of the guns when level and the axis of the trainer's telescope. Set the sight for zero range and azimuth. The line of sight should, for this position of sight, fall upon the "zero point," and when the sight is made to move up and down on its trunnions the line of sight should follow the elevation line on the screen. Then turn the sight in azimuth. Project the vertical and horizontal wires upon the screen at extreme positions of azimuth and at zero azimuth. By means of a straightedge and fine-point pencil draw these projections upon the screen. The points of intersection of the vertical and horizontal projection lines will determine the azimuth line of the sight, which should be perpendicular to the elevation line previously obtained, and intersect it in the "zero point."

(2) **The pointer's sights.**—Referring again to Fig. 104 it will be seen that a perfect installation of guns and sights will cause the axes of the telescopes to be projected at *l* and *k* when the sights are at zero range and centrally set in azimuth and the guns level. The

axes of the guns when elevated and depressed will follow the lines *E-F* and *G-H*, and the axes of the telescopes of the sights will follow the lines *N-M* and *P-O*. It is not strictly necessary, however, that the axes of the sights when level be projected at *l* and *k*. A slight lateral deviation from these points will make no material difference provided there is sufficient clearance in the peephole of the sight hood for the telescopes of the sights, and provided that they be projected on the line *K-L*. A lateral deviation from *k* and *l* may be caused by the guns not being installed in accordance with the exact measurement from the center line of the turret, as called for on the drawing, or by the center of the cam-plate bracket and the center of the pivot block being laterally misplaced to an equal extent. A lateral deviation due to either of these causes, if small, will make no difference in the accuracy of the gun fire.

(a) The elevation plane of the sight must be parallel to the elevation plane of the gun.

(b) When the sight is moved in azimuth its axis should move in a plane parallel to the horizontal plane through the axis of the trunnions of the gun. This may be called the *azimuth plane* of the sight, and its intersection with the screen may be called the *azimuth line*.

(c) Starting from a position of level the axis of the gun and the axis of the sight must remain parallel through elevation and depression.

558. Method of testing.—Assuming that the guns are satisfactorily installed and their elevation lines are *E-F* and *G-H*: Level the guns with the trams. Starting with the pointer's sight for the right gun, set it for zero range and azimuth and project its axis on the line *K-L* of the screen, as at *l*. *Elevate the gun* and note whether the line of sight through the axis of the telescope follows the line *M-N*, then gradually *depress the sight* to level, noting whether the line of sight follows down the line. If this should be the case, the elevation plane of the sight is parallel to the elevation plane of the gun, and the condition stated in paragraph 557 is satisfied. If, however, the line of sight projects a new line, as it is depressed independent of the gun, a faulty sight installation is evident.

Next test the sight by moving it in azimuth. Project the vertical and horizontal wires upon the screen at extreme positions of

azimuth and at zero azimuth. An observer at the screen moves a square or straight edge until its edge is in the line of projection of the horizontal wires as directed by the observer at the telescope, when a fine line is drawn to the straightedge by another observer. In a similar manner draw the line of projection of the vertical wire. Through the points of intersection of the horizontal and vertical lines at the positions of observation draw a straight line. This is the azimuth line of the sight, and should follow the line *K-L* unless a variable convergence of the guns is shown by their elevation lines, in which case the azimuth line should be perpendicular to the elevation line of the sight.

In order to ascertain if the requirement of paragraph 557 (c) is fulfilled, project the axis of the gun upon the screen at any point, as *x*, and at the same time note the projection of the axis of the sight, as at *t*. Measure the distance x-c' from *C-D* and *l-t* from *K-L*; *l-t* should be equal to x-c'.

559. It has been found by experience in installing pointers' sights that the error most likely to occur is in the elevation plane of the sight. This error can be readily detected as follows: Scribe a straight line on a batten, and with the gun level and sight at zero range and azimuth, secure the batten at a convenient place on deck in a horizontal position, so that the horizontal wire of the telescope will be directed at the line on it. Note where the projection of the vertical wire cuts this line. Elevate the gun successively to various degrees of elevation. At each position of elevation of the gun bring the sight down to level, and note the points on the horizontal line of the batten found by the intersection with it of the projection of the vertical wire of the telescope. If in any position of elevation of the gun, the sight set for the corresponding range and brought down to level, the projection of the vertical wire is found to cut the line on the batten at the same point as with the gun level and sight at zero range, the plane of elevation of the sight is parallel to the plane of elevation of the gun.

CHAPTER XIII.

FIRING ATTACHMENTS AND GAS-EXPELLING DEVICES.

560. In U. S. naval guns the term "*firing mechanism*" is used to designate that part of the breech mechanism which directly explodes the primer and thus fires the gun. The "*firing attachments*" comprse those appliances, fitted to the gun and mounts, which put the firing mechanism in operation. The lock lanyard, electric firing battery, wires, terminals, firing key, etc., are attachments. Firing mechanisms are covered in Chapter XI.

561. Guns are fired by percussion and by electricity.—Percussion primers are used for guns of 3-inch caliber and below, while guns of large caliber use combination primers which may be fired either by percussion or by electric current.

For large guns electric firing is considered preferable, percussion firing being used only as an alternative. Electric primers shorten the *firing interval*, or the time that elapses between the instant the gun pointer wills to fire and the instant the projectile leaves the muzzle. This interval, which on the average is three-tenths of a second, has two factors: (1) The *personal factor* (which is much the greater), depending on the pointer's quickness and nerve, and (2) the *time consumed by the travel of the projectile along the bore and by the mechanical action of the firing devices.* With electric firing, the pointer's muscles act through less distance than when using percussion firing mechanism, and the passage of the current is more nearly instantaneous than is the action of the lock lanyard, sear, hammer, etc.; and this part, at least, of the firing interval is reduced.

562. Current for electric firing is furnished by motor generators or by storage batteries, connections being made so that either may be used as desired. The motor generators for this purpose, usually two in number, are located in the interior communication room of the ship, and take direct current from the ship's circuit. They deliver alternating current at 125 volts to the fire-control switchboard, where the various units of the battery,

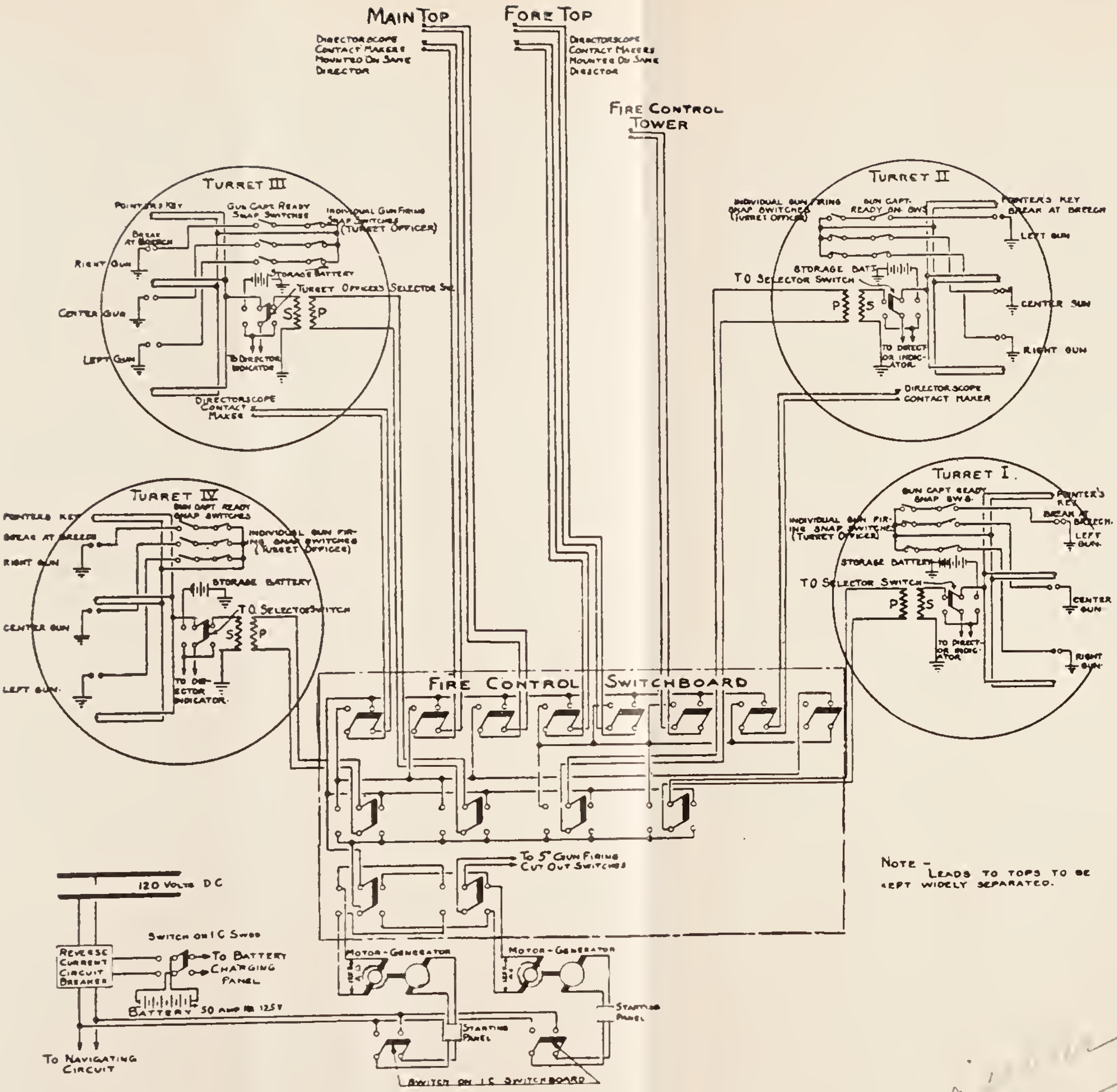
i. e., turrets and broadside groups, are cut in or out in accordance with orders from the fire-control officer.

563. Firing circuit for turret guns.—The wiring diagram for the firing circuit of turret guns on a battleship is shown on Plate I. It will be seen that direct current for the motor end of the motor generators can be taken either from the ship's mains or from a storage battery discharging at the rate of 50-ampere hours, with a voltage of 125.

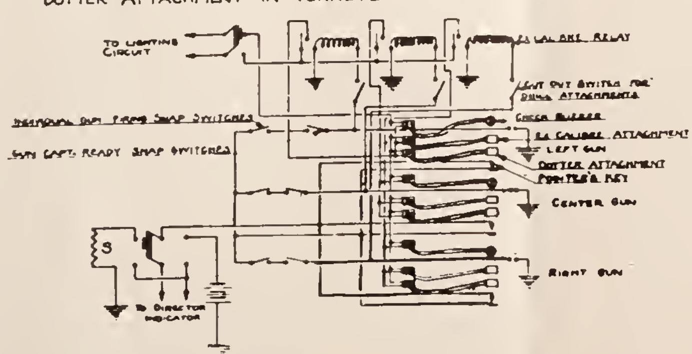
The motor generators serve merely to convert direct current into alternating current at the same voltage. The latter is led to the fire-control switchboard, which is shown to carry four cut-out switches, one for each of the four turrets. By closing these switches to the right, current is delivered directly to the primary coil of a transformer located in each turret. There the voltage is "stepped down" to 20 volts alternating current at the terminals, which is ample for firing the primers in the guns.

564. Located in the turret officer's booth in the turret is a selector switch whereby current for firing can be taken either from the secondary of the transformer or, in case of failure of the motor generator, from a storage battery. Following the diagram, it will be seen that the path of the current leads from this switch to the pointer's firing key at each gun, thence to the turret officer's snap switch (which is closed unless he wishes to cut out a gun from firing), then to the gun captain's ready switch (which is closed as soon as the gun is loaded and primed), thence to the terminals at the breech of the gun (which make contact as soon as the breech is closed and locked), and from this point to the primer bridge and thence to ground. It is apparent, therefore, that as soon as the gun is loaded, primed, and ready the only break in the circuit is the pointer's key, which is closed when the pointer's sight is "on" the target and the signal is given to fire.

565. The portion of the firing circuit described so far is sufficient to enable the guns to be fired by the pointers. This method or system of firing, known as "pointer fire," was the only one in use until a very few years ago. Within the last few years, however, a system of "director fire" has been introduced under which the guns are laid to a predetermined angle of elevation, and the actual sighting and firing is done from a station located usually aloft. The remainder of the firing circuit shown on Plate I covers



WIRING OF CHECK BUZZER, EX CALIBRE, AND DOTTER ATTACHMENT IN TURRETS FOR DRILL PURPOSES.



WIRING DIAGRAM OF FIRING CIRCUIT FOR TURRET GUNS.

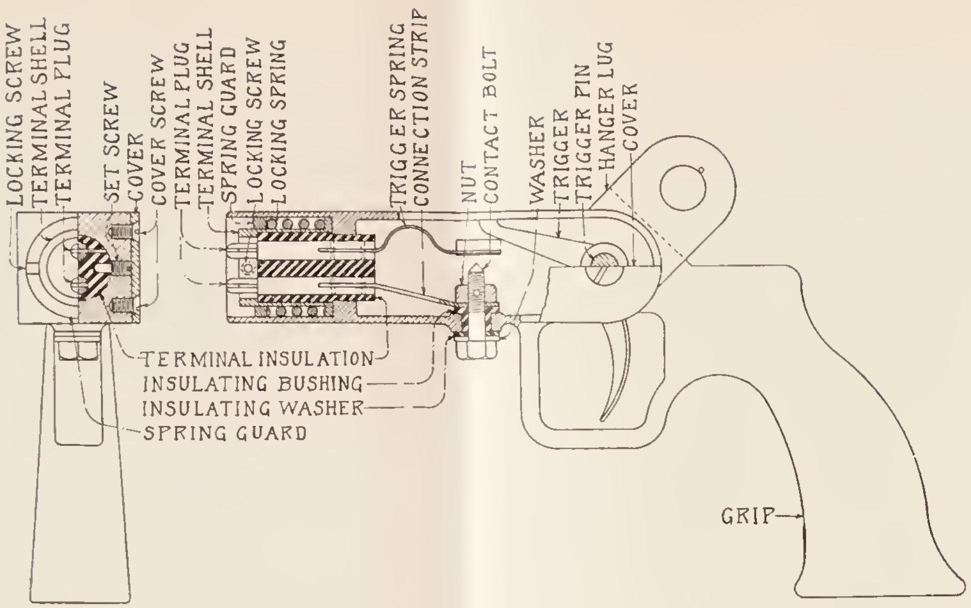


Fig. 1.—Pistol-Grip Firing-Key, Mark IV.

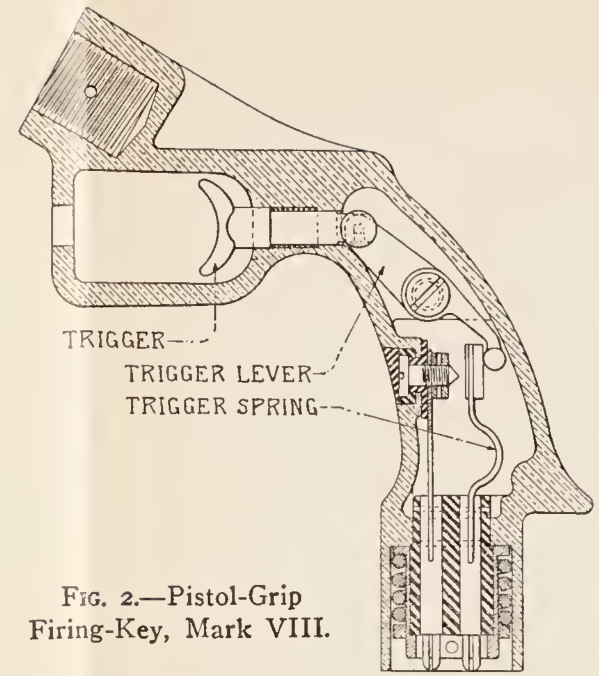


Fig. 2.—Pistol-Grip Firing-Key, Mark VIII.

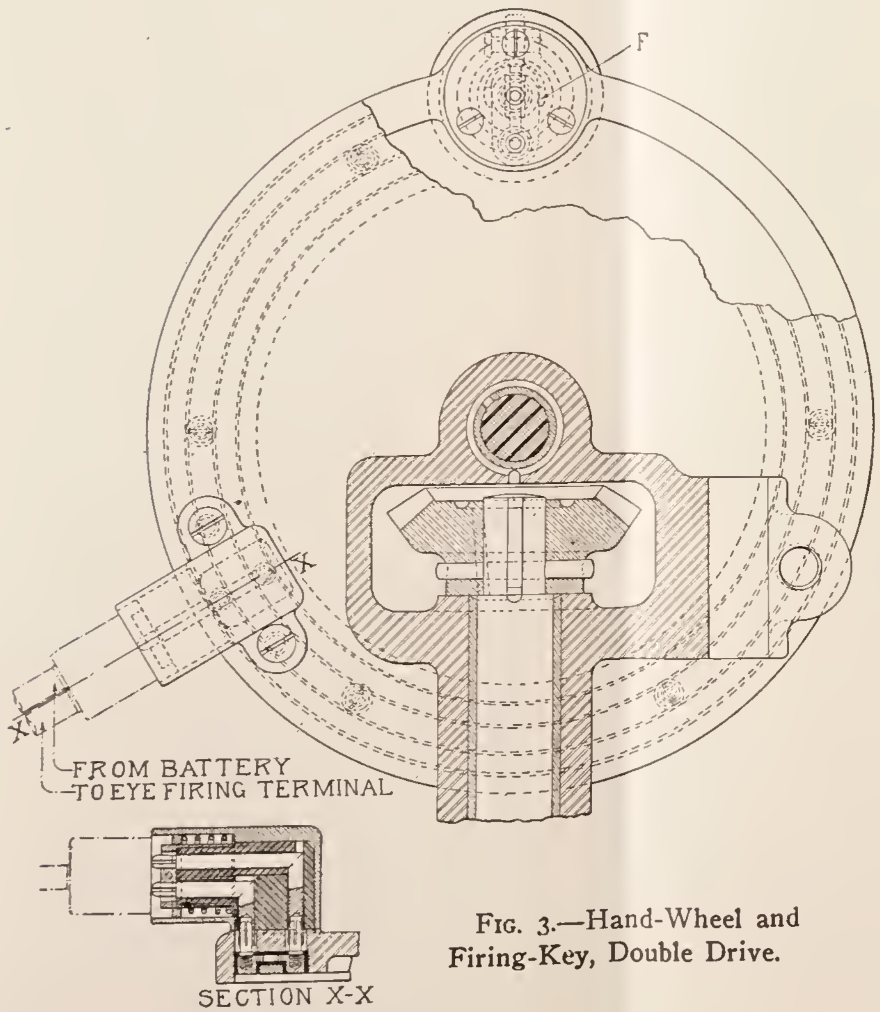


Fig. 3.—Hand-Wheel and Firing-Key, Double Drive.

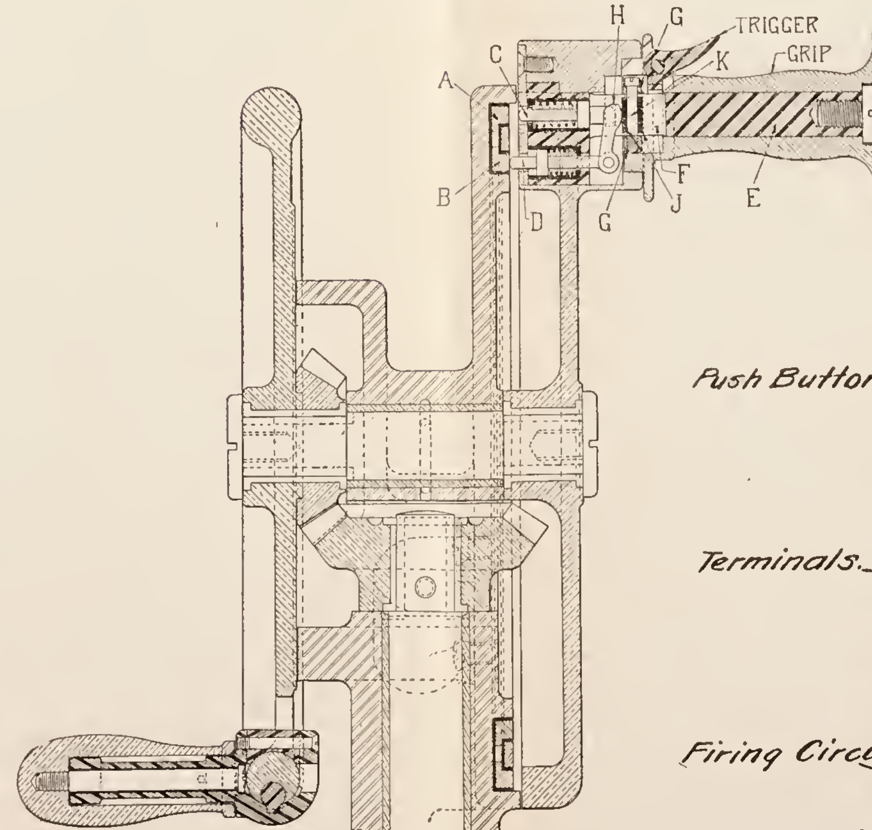


Fig. 4.—Hand-Wheel and Firing-Key, Double Drive.

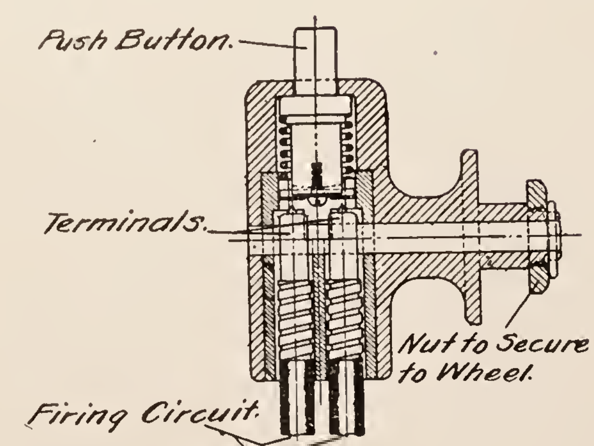


Fig. 5.—Push-Button Type of Firing-Handle Used on Two-Handed Drive Wheels.

FIRING-KEYS.

this director feature, and consists of the necessary switches and leads to the various directorscopes installed on the ship.

As will be seen from the diagram, directorscopes are located in the fire-control tower, the fore top, the main top, and in high turrets Nos. 2 and 3. By proper manipulation of switches on the fire-control switchboard, any one of these directorscopes can be made to control all turrets; or the control may be divided between two of them, the fore-top directorscope, for instance, being used for turrets 1 and 2, and the main-top directorscope for turrets 3 and 4.

When director fire is being used, the four turret switches on the fire-control switchboard are thrown to the left. The pointers' keys in the turrets are closed and held in that position, so that as soon as the guns are loaded and ready the only break in the circuit is the firing key at the directorscope. Firing is done "on the roll," that is, the directorscope operator closes his key at the instant his line of sight is brought on the target by the roll of the ship. The guns in the turrets, all laid to the desired angle of elevation, fire in salvo as the directorscope key is closed.

Attention is invited to the fact that all parts of the firing circuit receive full voltage except a short section of the leads in the turret. This is important, since the long leads to the different directorscopes might cause too great a drop in voltage to insure firing all primers if there were, for instance, only 20 volts across the motor-generator terminals.

It will be noted that both the fore and main top are provided with double leads to the directorscope. This is due to their exposed position. The extra leads are used as a stand-by in case one circuit should be cut.

566. Plate I shows also the wiring in the turret for dotter gear, ex-caliber, and other drill purposes. No special description of this material is required, since the diagram indicates clearly the various connections.

567. The firing circuit for broadside guns, together with the lighting circuit, is shown in Fig. 105, which represents a 5-inch 51-caliber gun and mount with firing attachments.

In order better to follow the various leads, a diagrammatic layout of the circuit is shown below the mount. It will be seen that current for firing may be taken either from motor generator or

battery, the transfer switch being thrown either way as desired. From this switch the path of the current leads to the pointer's firing key, then to the breech of the gun where a break in the circuit occurs until the breech is fully closed and locked, and thence through the primer bridge and primer wall to ground. The other end of the circuit is shown grounded at motor generator and battery.

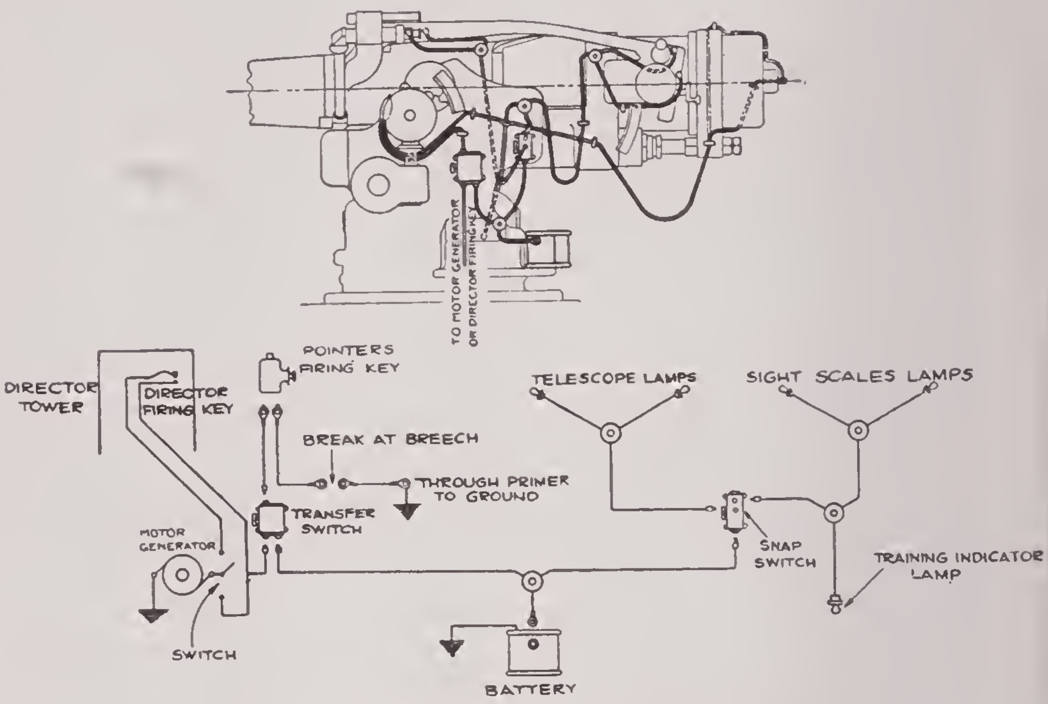
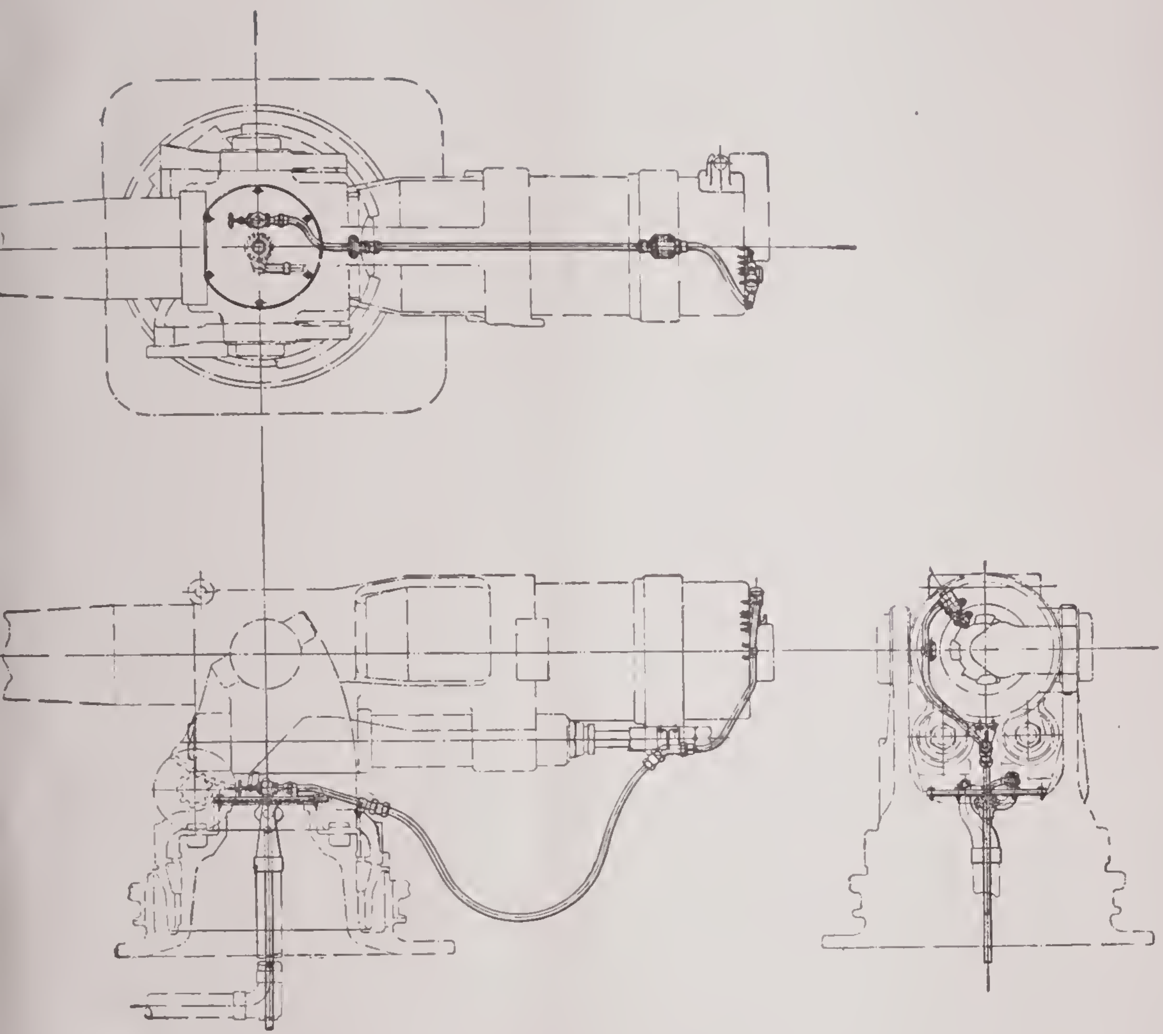


FIG. 105.—FIRING CIRCUIT FOR BROADSIDE GUNS.

568. Branching from the lead from battery is shown the lighting circuit, which serves to illuminate the cross-wires in the pointers' telescopes, as well as the sight scales and the training indicator at the base of the gun mount. It is apparent from the diagram that current for lighting is taken only from battery. The lamps, which are small and of low voltage, are grounded on one side in order to complete the circuit back to the grounded battery terminal.

569. For director firing of broadside guns, additional leads extend to the director tower. There the director is located, provided with a key for firing all guns of a group or broadside. These leads are indicated for convenience in Fig. 1, which shows the firing circuit of one gun only. Actually the complete wiring



Gas Ejector for Broadside Mount.

diagram would resemble somewhat the diagram for turret guns shown on Plate I, where one director can be cut in to fire a number of guns.

Referring to Fig. 105, by closing *downward* the switch shown in the lead from motor generator, the director is cut out, and current is provided at the gun for "pointer fire." Closing the switch *upward* cuts in the director and puts the circuit in readiness for "director fire." When the latter method of firing is used, it of course becomes necessary to close the pointer's firing key at the gun and maintain it in that position, so that the only break in the circuit will be at the director firing key.

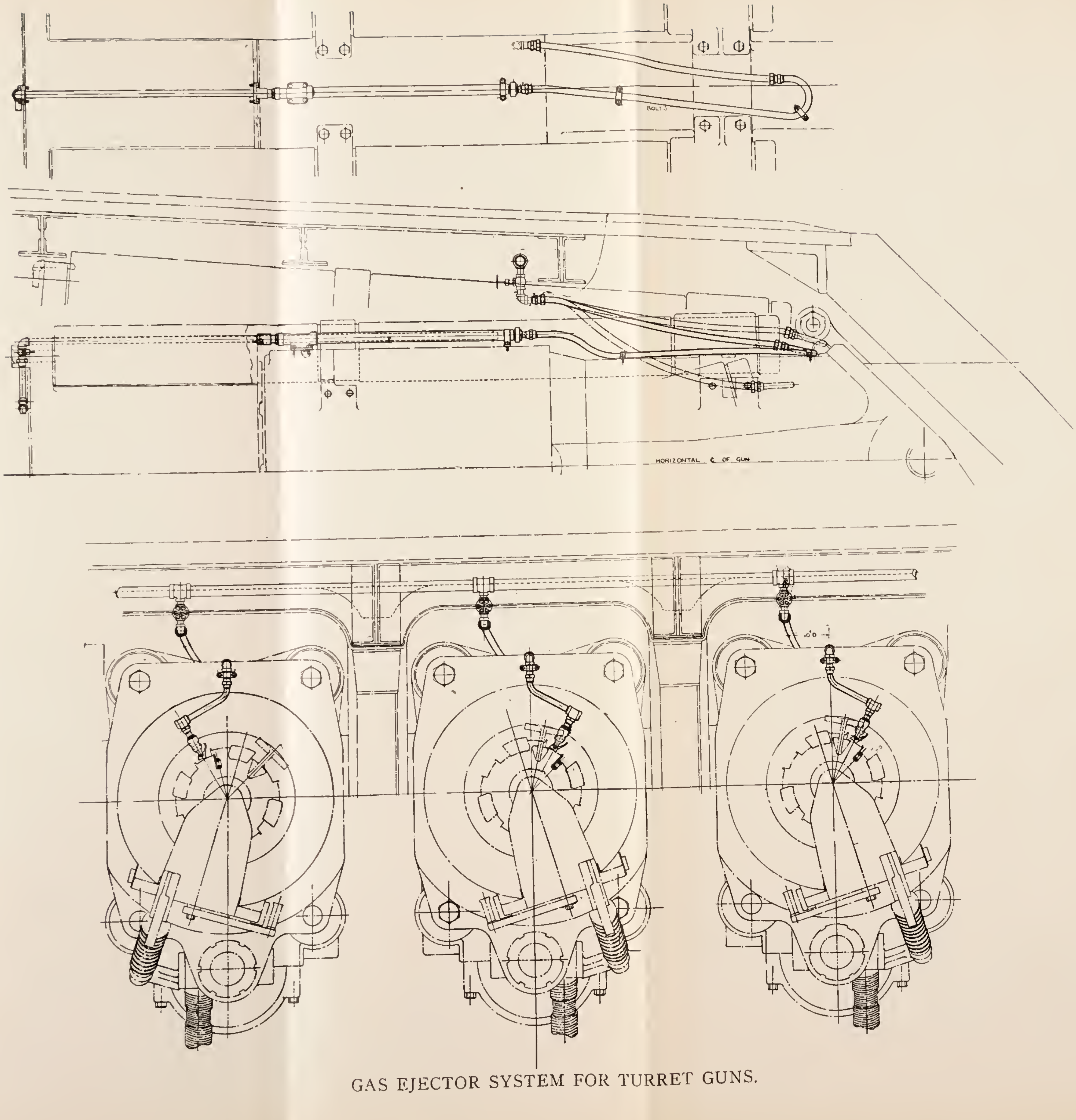
570. In all electric firing chief dependence is placed on the motor generator. The battery is used as a stand-by source of current in case of failure in the motor-generator line. For director fire it is apparent that the battery cannot be utilized at all, since its use is confined solely to the gun or turret where it is located, whereas director fire involves the firing of several guns in salvo, all from the same source of current.

571. Firing keys.—In the discussion of firing circuits above, reference has been made to the pointer's firing key, and to the directorscope firing key. Plate II shows a number of types of keys in use in the naval service.

The pistol-grip firing key, Plate II, Figs. 1 and 2, is used for guns having a one-wheel drive for the elevating gear. Fig. 1 represents a firing key used for secondary battery guns. It is attached to the mount by the hanger shown, and its operation is self-evident from the drawing. Fig. 2 is used with certain turret guns. The cables enter the butt of the grip, the forward end of the grip being attached to apparatus for firing percussion. For electric firing, the trigger is pressed in the usual way, thus completing the circuit through the key. For percussion firing the whole grip is pulled upward to operate the percussion mechanism.

Figs. 3 and 4, Plate II, show the firing key for a two-hand drive. The two brass rings *A* and *B* are insulated from each other, but may be connected through the pins *C* and *D* by pressing the trigger, thus completing the circuit for firing.

Fig. 5, Plate II, shows the form of firing handle generally used on two-hand drive wheels, such as are provided for 5-inch 51-caliber guns. The firing handle is simply a push button carry-



GAS EJECTOR SYSTEM FOR TURRET GUNS.

ing on its lower end a metal bridge to close the gap between the insulated firing circuit terminals. In its normal condition it is held clear of the terminals by means of a spiral spring. Pressing the push button serves to compress this spring and bring the metal bridge in contact with the terminals.

572. Care of electric firing attachments.—Batteries should be frequently tested with a voltmeter, the various parts of the circuit with a battery tester, and the circuit as a whole with an ammeter. At regular intervals the resistance of each part of the circuit should be measured, and the measurements recorded for comparison with subsequent readings. Actual tests should also be made by firing primers. Unless the electric firing connections are perfect and securely held in place, there will be frequent failures to fire, due to insufficient current passing through the primer.

The best test (and the only sure one) of electric firing connections and battery strength is the firing of primers. The battery tester, ammeter, voltmeter, Wheatstone bridge, etc., are mainly useful in locating faults.

573. The faults most frequently found in the circuit are broken wires, or grease or other foreign matter in the connections. The firing of the gun will sometimes jar out the plugs, and as it is important that this should not occur, they must be well secured. Particular care must be taken to see that the primer seat, the primer, and all contacts are perfectly clean and free from grease or oil. Whenever there is danger of a short circuit, the parts should be covered with insulating tape. The failure of the primer when using electric firing is generally due to poor contaits.

Gas-Expelling Apparatus.

574. Flare-backs.—The smokeless powder used in the United States Navy leaves in the bore, after firing, an inflammable gas (carbon monoxide) which sometimes becomes ignited on opening the breech plug, causing what is called a "flare-back" (see Art. 25). With bag guns this "flare-back" is very dangerous, since the powder charges may be ignited by it in loading, as happened with disastrous results in the after 12-inch turret of the U. S. S. *Missouri* on April 13, 1904.

575. Gas-expelling device.—To guard against flare-backs, an air blast is now fitted to all bag guns, in order to blow out through

the muzzle the gases remaining in the gun after firing. Plate III shows the gas-expelling device fitted to a 5-inch gun, and Plate IV shows a similar device for 14-inch and 16-inch turret guns.

Referring to Plate III, air at about 150 pounds pressure is brought from an *accumulator* through a brass pipe extending up through the pedestal. At the top of this pipe, and directly beneath the gun, is a stop valve by means of which the air pressure can be placed on the gun or shut off as desired. Beyond this valve extends a section of flexible metal hose, of length sufficient to allow for the

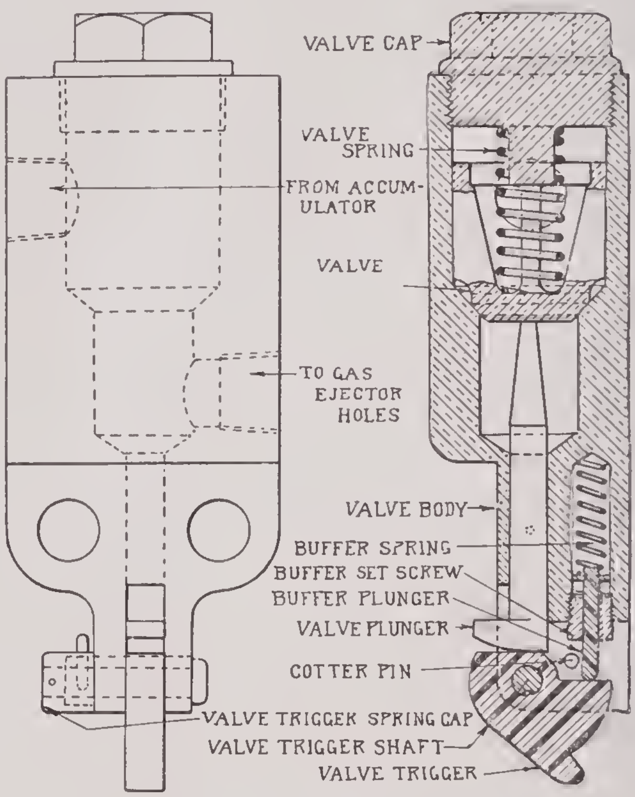


FIG. 106.—GAS-EJECTOR VALVE.

recoil of the gun. The after end of this hose is coupled to a section of copper piping, which in turn leads to the *gas-ejector valve* located on the breech of the gun. Fig. 106 shows this valve.

576. Operation.—The operation of the "gas-ejector" valve can be readily understood from the figure. The valve seats downward, being held against its seat by a spiral spring and by the air pressure in the line. Against the bottom of the valve rests one end of the "valve plunger," the other end being in contact with the cam-shaped "valve trigger." There is a cam plate on the

breech plug, so located that the first motion of withdrawal of the plug in opening brings this plate against the valve trigger, revolving it and thereby pushing the valve plunger upward. This latter motion unseats the valve, allowing air to rush past it to a circular pipe surrounding the breech of the gun, and thence through holes spaced 60° apart leading to the screw box. As soon, therefore, as the breech plug has rotated sufficiently to unseat the " gas check," air is forced out through the muzzle of the gun, taking with it the gases lingering in the bore. When the breech is fully opened, and the bore is seen to be clear, a member of the gun crew touches the trigger of the gas-ejector, thus shutting off the air. During firing, air pressure is kept turned on and maintained on the piping up to the gas-ejector valve.

577. **Automatic closing valves** are installed in air lines to guns in exposed parts of the ship such as the upper decks. The reason for this is that the lines are unprotected by armor, and should they be pierced the pressure in the accumulators would quickly be lost due to escape of air. These valves are so adjusted that the fall of pressure due to opening the breech of a gun does not affect them, but an abnormal fall, such as that caused by a rupture of the air line, causes them to close immediately.

578. **The gas-ejector system for turret guns,** shown on Plate IV, is similar to that described for broadside guns. Air from the accumulators is led to a point overhead near the roof of the turret, where an athwartship pipe distributes it to the three guns. It will be noted that a different means is provided in this case to allow for recoil. Instead of a bight of flexible metal tubing, each gun is fitted with a telescoping air line, extending to the breech where the gas-ejector valve is located.

579. **Air pressure in turrets.**—It is customary to close the openings to the turret and maintain the turret chamber under a low air pressure from the ship's ventilating system during firing. This is done as an auxiliary, and in addition to the above-described gas-expelling device, but never replaces it.

CHAPTER XIV.

ARMOR.

Historical.

580. The first publicly recorded proposal to sheath the hulls of naval vessels with a metal shield was made by Sir William Congreve in *The Times* in London on February 20, 1805. A similar proposal was later made by John Stevens, of Hoboken, New Jersey, in 1812. Nothing came of these proposals for years, but in spite of such lack of encouragement, John Stevens and his sons undertook a series of experiments by which they determined the laws of penetration of iron plates by cannon balls and the maximum thickness of iron plate necessary to defeat any known gun. In 1842, Robert L. Stevens, one of John Stevens' sons, presented the results of these experiments, and a new design of a floating battery, to a committee of Congress. These experiments of Stevens aroused great interest both in America and Europe. In 1841 the Frenchman, General Paixhan, also pointed out the necessity of armoring ships, and in 1845 Dupuy de Lome designed an armored frigate for the French Government. These proposals resulted in the laying of the keel of the armored "Stevens Battery" in Hoboken in the spring of 1854, followed in a few months by four keels in Toulon, and but a few months later by three more in England. One of the French floating batteries was fittingly named the Congreve. During the following year occurred the first engagement in which armored vessels participated—the bombardment of the Kinburn forts in the Crimean War by three of the French batteries.

Iron Armor.

581. The only metal, practicable and available in suitable quantity, at this period, was iron, wrought or cast, and all experiments showed that the wrought iron was far superior, pound for pound, to the cast iron, in defeating projectiles. Wrought iron was therefore adopted for marine use, and these first ironclads were protected by solid plates between 4 and 5 inches thick backed by 36 inches of solid wood timbers.

The most costly experiments were carried out, especially in Europe, where the iron industry was most highly developed, to improve the resisting power of wrought iron armor. Tests were made of laminated iron plates, with the laminations in contact, and with wooden timbers between, but in all cases, single plates gave greater resistance per pound of protection.

During the Civil War most of the armor employed on American vessels was laminated wrought iron, but this was necessitated by lack of facilities for manufacturing single plates of proper thickness, rather than by any superiority for that type of armor.

Proposals for the production of face-hardened armor were early made. At first these proposals were to face wrought plates with cast or chilled iron plates, but as these schemes involved the same loss of efficiency as was exhibited by laminated plates, and because of the insecurity of the bond between the plates, the hard plate failed to secure the full support of the tough back, they all failed to compare favorably with single iron plates. But as far back as 1863, a Mr. Cotchette proposed, in England, the welding of a 1-inch blister steel plate to a 3-inch wrought iron plate; and later, in 1867, Jacob Reese of Pittsburgh, Pa., patented a cementation compound which he stated could be used for cementing and hardening armor plate. Efforts to carry out these proposals failed, for many reasons, primarily because the general development of metallurgy was not equal to the task. It should be remembered that the Bessemer process of making steel in a converter was developed between 1855 and 1860 and that the Siemens-Martin process of making steel in an acid open hearth was developed in France and England a few years later, each process being brought to the United States several years after its European development.

Cast iron has been used for armor in land fortifications, where weight is of slight importance, but as stated above, it has never been applied to naval vessels. The most prominent example of cast iron armor is the famous Gruson turret. These turrets were made of large iron castings, the exterior surfaces of which were chilled by heavy iron chills in the moulds; and were of an oblate-spheroidal shape. Due partly to their shape, but also to the fine quality of the iron and their great thickness, these turrets were considered of great value and were used extensively in protecting

European frontiers. The first Gruson turret was tested in 1868 by the Prussian Government.

Steel Armor.

582. In 1876 gun power and projectile quality had so increased that about 22-inches of iron was necessary to accomplish the defeat of a projectile from the heaviest cannon, but in that year occurred, at Spezia, a trial which revolutionized armor manufacture and permitted a reduction in thickness. In these trials a 22-inch mild steel, oil-quenched, plate manufactured by the great French firm of Schneider et Cie. completely outclassed all its iron competitors. This plate is reputed to have contained about .45 per cent carbon and to have been hammered down to the required thickness from an ingot about seven feet high. The process of manufacture was kept secret. This steel plate, while possessing superior ballistic resistance, was more prone to breaking up and this difficulty led to the next real development, which logically resulted from efforts to combine the hardness of steel in the face of a plate with the toughness of iron in its back. The steel used in these plates was made in Siemens-Martin open-hearth furnaces.

Compound Armor.

583. Thus resulted a new type of armor—the compound type—the two principal examples of which were the Wilson-Cammel *compound* plate in which an open-hearth steel face was cast on top of a hot wrought iron back plate, and the Ellis-Brown *compound* plate in which a steel face plate was cemented to an iron back plate by pouring molten Bessemer steel between them. In both these processes, which were English, the plates were rolled after compounding. For the next ten years there was no especial development in armor manufacture other than minor improvements in the technique of manufacture, and great competition and controversy existed as to the relative quality of all steel and compound armor. The all-steel armor was a simple steel of about .30 per cent to .40 per cent carbon, while the steel face of the compound armor contained between .50 per cent and .60 per cent carbon. These two classes of armor, their comparative value depending largely on the skill with which they were made, were

approximately 25 per cent superior to their wrought iron predecessor, that is to say—a 10-inch all steel or compound plate would resist the same striking energy that a 12.6-inch iron plate would withstand.

Nickel-Steel Armor.

584. The next step in advance occurred about 1889 when Schneider introduced nickel into all-steel armor, and with the advent of nickel-steel armor, began the complete elimination of compound armor. The nickel greatly increased the strength and toughness of steel. The amount of nickel in the first few examples of nickel-steel armor varied between 2 per cent and 5 per cent, but finally settled down to about 4 per cent. At about this same time oil and water quenching were successfully applied to armor plates by Schneider. After forging under a hammer, and annealing, the plate was heated to a tempering heat and its face was then dipped for a short distance in oil, this tempering being followed by a low temperature anneal. These improvements resulted in a further increase of about 5 per cent in the resistance of armor, that is to say, a 10-inch nickel-steel treated plate equalled about 13 inches of iron.

It was at this stage of development that the manufacture of armor was undertaken in America, by the Bethlehem Iron Company, under the supervision of Mr. John Fritz, and shortly afterward by the Carnegie Steel Company, under Schneider patents, and the first deliveries of armor for the old *Texas, Maine, Oregon*, etc., consisted of heat-treated nickel steel, containing about .20 per cent carbon, manganese about .75 per cent, phosphorus and sulphur about .025 per cent and nickel 3.25 per cent.

Harvey Armor.

585. In 1890 the next great improvement was begun by the introduction of the Harvey process which was first applied to armor when a Creusot 10½-inch steel plate was Harveyized at the Washington Navy Yard. This process, the invention of H. A. Harvey of Newark, N. J., consisted in carburizing or cementing the face of a steel plate by heating it and holding it to a very high temperature (*about that of molten cast iron*) for from two to three weeks, with the face to be hardened in intimate contact with

a bone charcoal or other carbonaceous compound. The result of this treatment was to raise the carbon content of the face to between 1 per cent and 1.10 per cent, with a gradual reduction in carbon content beneath the surface until the effect of the carburization vanished at a depth of about 1-inch. Later the plate was oil-quenched and then water-quenched, both operations at a uniform temperature throughout the plate, the result being that the super-carburized face assumed a very hard condition, while the back of the plate was toughened. In other words, the face of the plate was *super-hardened because of its higher carbon content.*

In 1887 Tressider patented, in England, a method of improving the chilling of the heated surface of a plate by forcing against it, under considerable pressure, a dense spray of fine streams of water. This scheme improved on the previous dipping because it kept fresh cool water against the heated surface, thus facilitating the extraction of heat by eliminating the retarding influence of the layer of steam which would otherwise have been formed. This water spraying was now combined with the Harvey process and we have the nickel steel, cemented, oil-tempered and water-sprayed, face-hardened armor known as Harveyized armor and sometimes simply Harvey armor.

A typical chemical analysis of the Harvey armor of this period shows the carbon content to have been about .20 per cent, manganese about .60 per cent and nickel about 3.25 per cent to 3.50 per cent.

Shortly after the adoption of the Harvey process it was shown that the ballistic quality of a plate could be improved by reforging, after cementation. This reforging, giving a reduction of from 10 to 15 per cent, was conducted at a low temperature and was first adopted because it gave more precise regulation of thickness, improvement of surface finish and some refining of the structure in advance of heat treatment. This process was patented by Mr. Corey of the Carnegie Steel Company, under the name "double forging."

Harveyized armor immediately established its superiority over all other types. The improvement amounted to another 15 per cent to 20 per cent increase in resistance, 13 inches of Harvey armor equalling about 15.5 inches of nickel-steel armor.

Krupp Armor.

586. During the eighties, another alloying element, chromium, had been introduced into small crucible heats of steel, and the resulting alloy was found, when properly heat treated, to possess great hardness. Steel makers, in spite of persistent efforts, failed to produce large nickel-chrome steel ingots, or to properly forge and treat them when produced, until the great German works, Krupp, solved the problem about 1893.

Krupp also adopted the cementation process for armor, but instead of using solid hydrocarbon as in the Harvey process, used a gaseous hydrocarbon; illuminating gas being passed while hot across the face of the heated plate. This gaseous cementation has been frequently used, but has been gradually superseded by the use of solid hydrocarbon. Gaseous cementation was used at Bethlehem in 1898 but has since been abandoned and is not now used on American armor plates.

At about the same time Krupp developed a process of deepening the hardening on one side of a cemented steel plate. To do this, the plate was imbedded in clay or loam, with the cemented side exposed, and then the exposed face was subjected to a very hot and quick heat. As the heat penetrated gradually, the exposed face became much hotter than the back, thus permitting "*decremental hardening*" by water spraying. A piece of steel heated above a certain temperature, will become very hard if quenched in water, while its physical properties will be little affected if it is quenched when below that temperature. For the sake of convenience, let us call this certain temperature a critical temperature. Now as the face of the plate is heated above this critical temperature, there will always be a plane in the plate at the critical temperature, and as the heating is continued this plane of critical temperature will gradually travel inward toward the back, eventually reaching the back if the heating is continued long enough.

However, the plane of critical temperature was only allowed to sink between 30 per cent and 40 per cent of the thickness, and when that position was reached, the plate was hurriedly withdrawn from the furnace, put in a spraying pit, and subjected to a powerful spray of water, at first on the superheated side and a moment later on both sides, the double spraying being done to prevent, as much as possible, the warping which a spray on but one side would produce.

This process, called decremental face hardening, produces a very hard face, between 30 per cent to 40 per cent of the plate's thickness, and at the same time leaves the other 60 per cent to 70 per cent of the thickness in its original tough condition. It should be specifically noted that this method of hardening depends on the *decremental heating* and does not necessarily involve any variations in carbon content. In other words, in this type of face hardening, the front portion of the plate is *super-hardened because of its higher temperature*, the depth of the hardening being subject to regulation, and greater than the depth of cementation, if desired.

The process of face hardening, being the final treatment, was, of course, applied after the plate had been heat treated to refine the grain and produce a fiber in the steel to increase its strength and ductility.

The success of the Krupp process was immediate, and all armor manufacturers soon adopted it. In all plates thicker than about 5 inches, the Krupp armor was about 15 per cent more efficient than its immediate predecessor, Harveyized armor; 11.9 inches of Krupp being about equal to 13 inches of Harveyized armor. The Krupp process was applied to armor for American vessels in 1900. Most of the armor made for the past 25 years has been Krupp cemented armor.

During the past 15 years, various slight improvements have been made in the technique of manufacture; and it is, as now made, possibly 10 per cent better, ballistically, than it was during its early use.

Present Manufacture of Krupp Cemented Armor.

587. Carbon being the principal hardening element, the natural tendency is to carry the carbon as high as is possible. The higher the carbon, however, the more difficult becomes manufacture, tears appear in the forging, fibering the plate becomes more difficult, and the plate becomes brittle, making it liable to cracking and excessive spalling (detaching of surface fragments) on ballistic test. The addition of nickel increases the toughness of the plate, and permits it, when properly treated, to be fibered; while the chromium adds hardness without the extreme brittleness which would accompany this hardness if produced solely by carbon. The chromium also renders the steel particularly sensitive to

heat treatment and thus facilitates the final decremental water hardening.

A typical chemical analysis of a modern Krupp cemented plate is as follows:

Carbon	.35
Nickel	3.90
Chrome	2.00
Manganese	.35
Silicon	.07
Phosphorus	.025
Sulphur	.020

In this connection it is interesting to note that when K. C. armor was first introduced into America, the plates ran about .27 per cent carbon, 3.75 per cent nickel, and 1.75 per cent chromium. The increase in carbon and chromium is indicative of the improvement in metallurgical skill and the increased resistance of modern K. C. armor which has occurred since its development.

The modern process of manufacture is briefly as follows:

1. Melt in a basic open-hearth furnace and pour into an iron or sand mould. An ingot for a three-gun turret port plate is about $42'' \times 150'' \times 250''$ and weighs about 425,000 pounds, while the ingot for a belt plate is about $26'' \times 132'' \times 200''$ and weighs about 200,000 pounds. Dimensions of ingot are varied to suit conditions. (See Plate I.)

2. Strip while still hot, clean, prepare for forging.

3. Reheat for forging, and forge under a powerful hydraulic press to within about 15 per cent of final thickness; cut off top discard of 30 per cent. The forging reduction is about 3 to 1. (See Plate II.)

4. Anneal, to eliminate forging strain, and to put the steel in a partially fibrous condition to prevent cracking in cooling.

5. Super-carburize—this takes from 10 to 14 days. (See Plate III.)

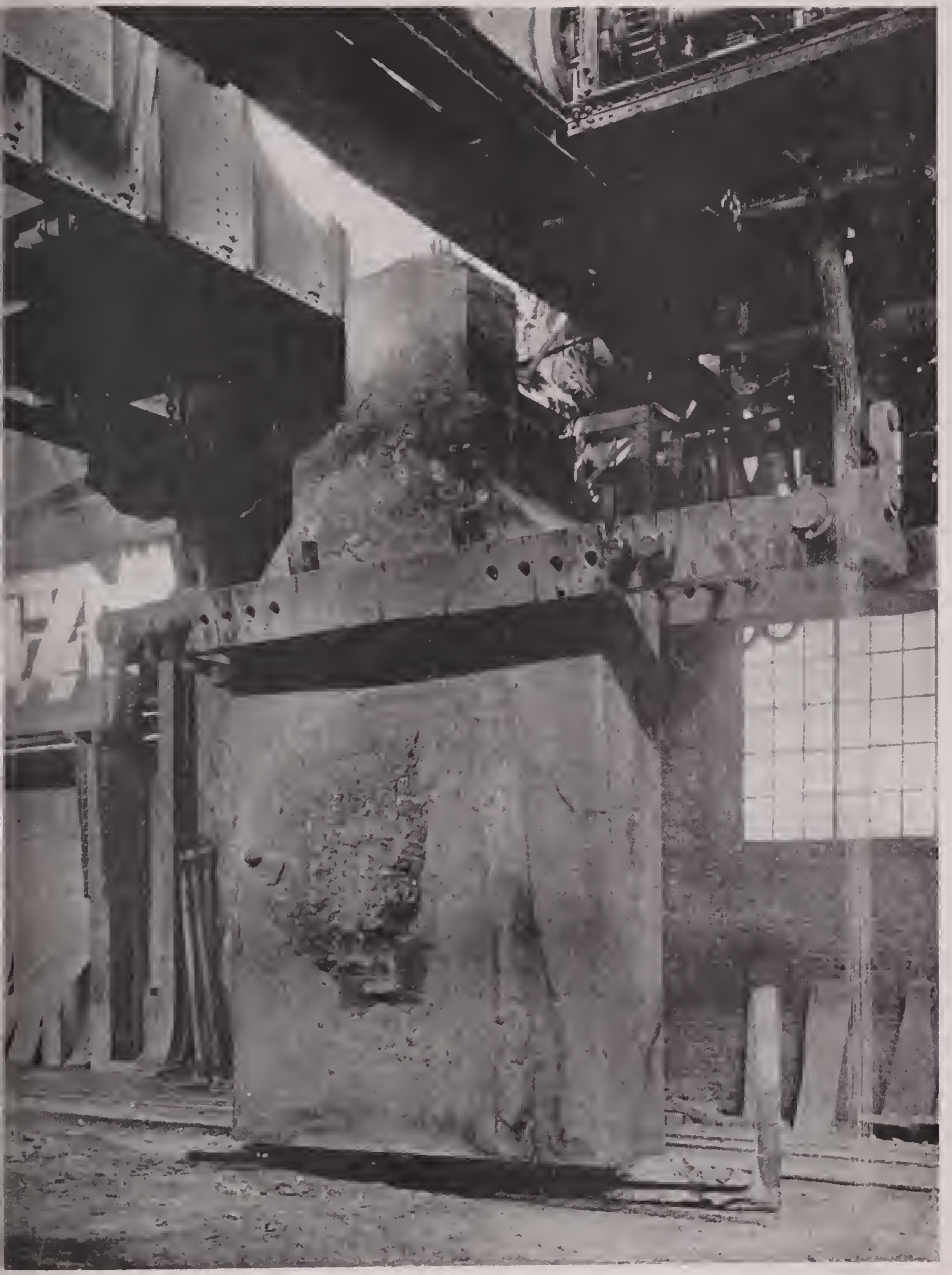
6. Reheat and reforge to nearly final thickness.

7. Anneal to prevent cracking while cooling.

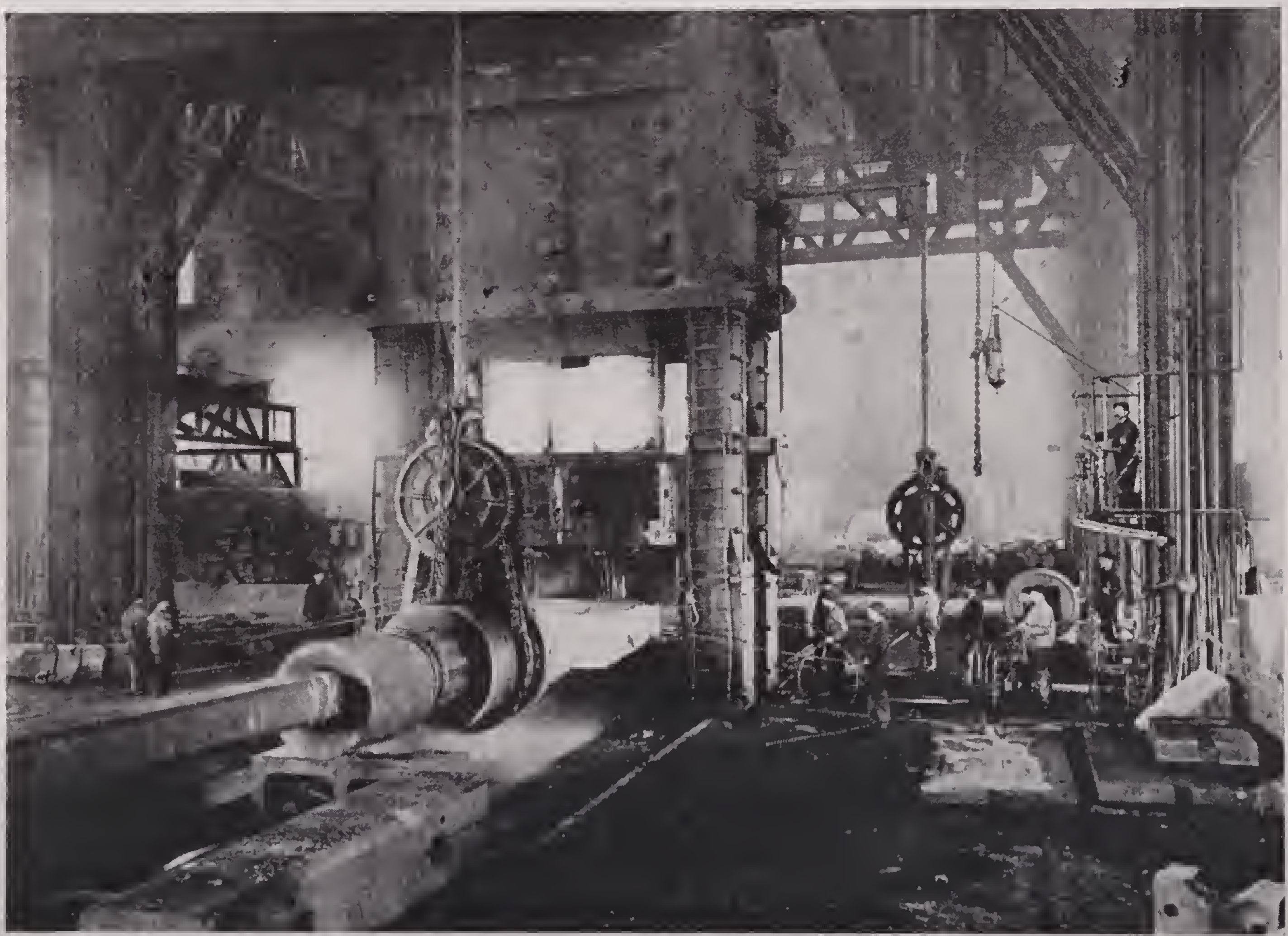
8. Fibering treatment, generally consisting of several treatments to develop the proper physical properties.

9. Machine to rough dimensions.

10. Reheat and form to shape.



ARMOR INGOT, WEIGHT ABOUT 400,000 POUNDS, BEING CARRIED ON TWO CRANES TO BE FORGED.



FORGING A "BELT PLATE" UNDER A 10,000-TON PRESS.

THREE PLATES LOADED ON FURNACE BOTTOM READY TO RUN IN FOR "CARBURIZING."

A Side Armor, or "Belt" Plate, on the "Spray" After Final Water Hardening.

11. Reheat front face to a temperature above the critical temperature for the depth of chill desired, keeping the back of the plate below the critical temperature, and harden under spray. (See Plate IV.)

12. Give a slight heat and rectify curvature.

13. Finish machine.

Non-Cemented Armor.

588. From the discussion of decremental hardening as applied to K. C. armor, it is quite apparent that a plate may be hardened without prior cementation. It should be mentioned here that the carburized face is much more liable to tearing and cracking during forging and bending to shape than is the other portion of the plate, a condition which renders the fabrication of thin plates more difficult than thick ones. These facts led the Bethlehem Steel Company to undertake the manufacture of armor by the general Krupp process without cementation. Later the Midvale Steel Company adopted the same idea. Such armor is generally referred to as Krupp non-cemented or K. N. C. armor. In structure, this armor differs appreciably from K. C. armor. For instance, there is no super-carburized face, and the chill itself is generally harder and somewhat deeper. And there is a further difference in chemical composition, in that, while the carbon and chrome may be somewhat higher, the nickel may be equal or lower, as compared to K. C. armor. Non-cemented armor is fully equal, ballistically, to K. C. armor, can in fact be made of superior ballistic resistance, but it has an unfortunate tendency to spalling, both on projectile impact, and even from internal strain. It was this tendency to spalling which led to the abandonment of the process after a few years of use. A typical analysis shows carbon as high as .50 per cent, with nickel at 3.5 per cent and chromium at 2.30 per cent to 2.50 per cent.

Class A Armor.

589. The general term *Class A* armor is applied, in the American Navy, to all face-hardened armor, whether Krupp cemented or Krupp non-cemented.

Summary.

590. It will be seen from the preceding review that each change in armor has *added* something, and that modern armor contains all the essentials of each successive product. First, for marine use, we had the simple wrought-iron armor, which was later developed into compound iron-steel armor. Then all-steel armor displaced the compound armor, and was in turn improved by the addition of nickel. Next we have a return to the hard face principle, but with homogeneous structure, in the application of Harveyizing. And finally we have the introduction of chromium and the development of decremental hardening as applied to both cemented and non-cemented plates.

The manufacture of efficient armor requires not only a high quality of metallurgical skill, but also most expensive tools and equipment. The various improvements in its quality and manufacture have, therefore, been as closely related to the inventions and discoveries of metallurgy, as to the commercial growth of the general steel industry. A knowledge of the nature and dates of the various stages in its development, therefore, gives the ordnance student an excellent picture of the evolution of the use of iron and steel. Frequently the demands of the ordnance engineer have caused developments in metallurgy which have had far-reaching commercial application, but more frequently the general improvements made by the metallurgical engineer and chemist have opened new vistas to the designers of ordnance.

Inspection and Test.

591. All during manufacture the processes are watched to insure uniformity in procedure and product. Chemical analyses are made to insure homogeneity in the metal, and test specimens are taken out of the ends of the plates to determine the uniformity of the physical properties. Finally, after water hardening, fragments called coupons are broken off diagonally opposite corners, in order that a microscopical examination may be made of the internal structure. (See Plate V.)

Plates are arranged in "groups," each containing from 600 to 1200 tons, and after water hardening a plate is selected from the group, sent to the proving ground, and there tested ballistically. If successful, the group is passed to completion, if unsuccessful,

COUPON FROM 10-INCH PLATE. BROKEN COLD UNDER PRESS.

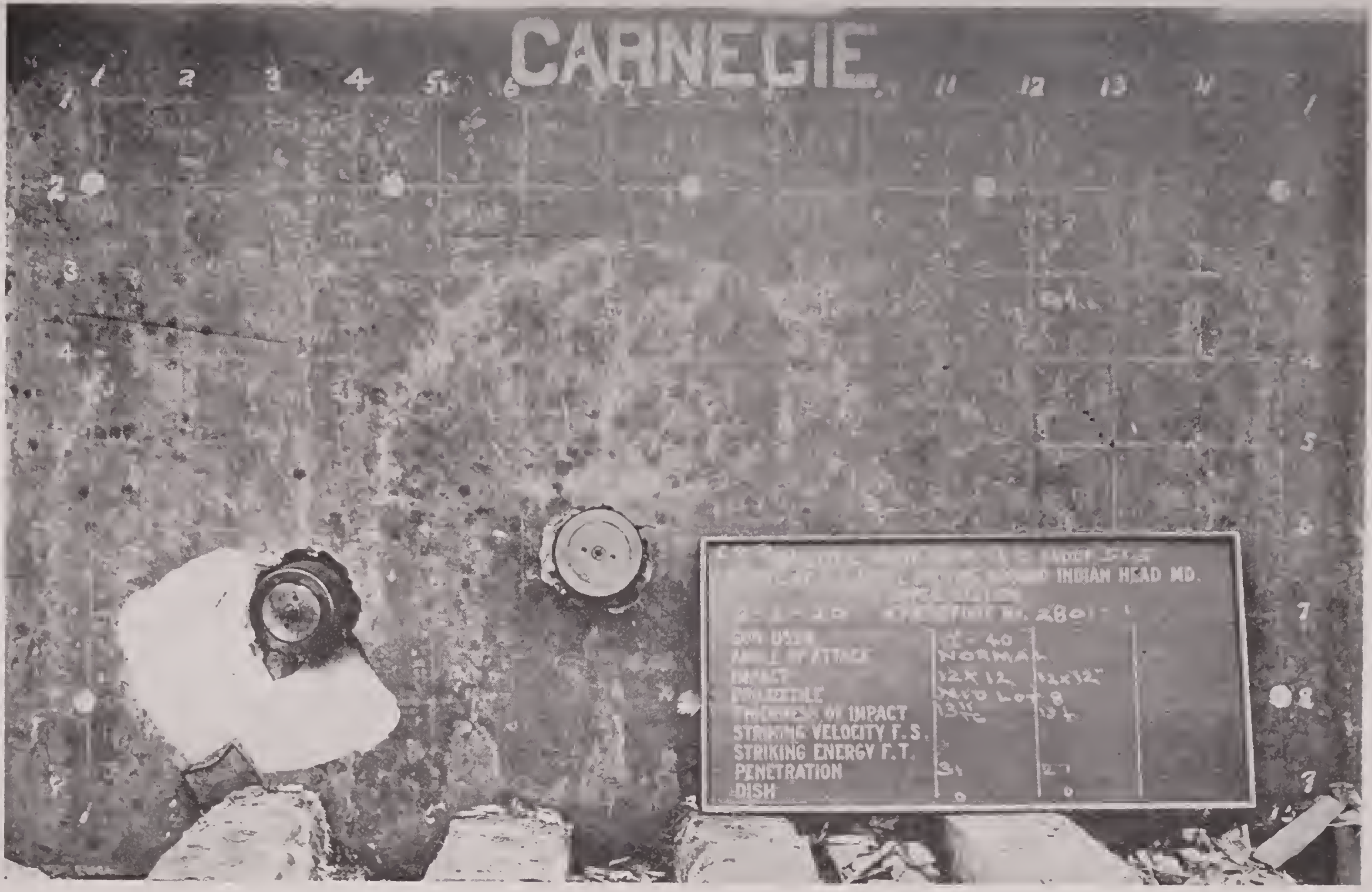
the group is rejected for retreatment. The ballistic test consists, at present, in subjecting the plate to the normal impact of two major caliber A. P. projectiles at specified velocities, the velocity depending on the gauge of the plate and size of the projectile. This relation will be discussed under the heading of "penetration."

The Ballistic Test.

592. In testing and experimenting with armor, great energies must be absorbed. For instance, a 16-inch projectile striking normally at 2000 f. s. delivers about 60,000 foot-tons. Assuming that the plate is 10 ft. × 20 ft. × 15 in., that gives about 300 foot-tons per square foot of plate area, or about 1100 foot-tons per ton of plate. The structure to which the plate is attached must, therefore, be of great strength. Such structures are called "*plate-butts.*" (See Chapter XVII, Plate II.) Similar structures used for testing the action of projectiles against plates are called "*projectile-butts.*"

Particular attention must be given in conducting *all* impact tests to eliminate, so far as is possible, all movement of the attacked plate, or in other words, to preserve the rigidity of the structure as a whole. This is particularly true when plates are attacked at other angles than normal, for in such cases there may be most powerful end thrusts, which, if uncontrolled, will permit end movement and therefore subject the projectile to uncontrolled and unknown "whip," thereby vitiating the value of the test. Plate VI shows an armor plate after undergoing test.

The routine ballistic test has been mentioned previously. The two shots required are for the *purpose of determining whether the manufacturer's current manufacturing methods in general, and the group represented, in particular, are up to the required standard.* That condition having been established, and the group's acceptability settled, it is customary to attack the plate with one or two additional shots to determine its precise "*ballistic limit.*" To determine this ballistic limit thé velocity of impact is increased until penetration is just or nearly secured. Experienced personnel can, with ordinary armor, generally secure this result (after two ballistic test shots) in two more shots, and sometimes even with one shot.



A Ballistic Test Plate.

In experimenting with and testing armor it is the *ballistic limit* which is the significant figure. How it is expressed will be shown later. But it is easily seen that by always working for it, a record can easily be compiled, in time, which will show, not only the general average of performance, but also the peak of performance. And by always carefully investigating the plates which give the greatest resistance, the general standards may be raised.

Penetration.

593. Great discussion took place in the early days of ship armor as to whether armor could best be defeated by "racking" or "punching." Racking was produced by very large solid ball shot at low velocity and resulted in knocking plates off the ship's side, thus exposing her vitals; and punching was produced by elongated projectiles, at high velocity, and resulted in perforation and the immediate attack of the ship's vitals. This discussion was settled during our Civil War very emphatically, and later in the *Huascar-Cochrane* and *Blanco Encalado* engagement; for the shots which secured decisive effects, practically without exception, were piercing shots. This discussion finds its echo in more recent controversies concerning the relative merits of armor-piercing and high-capacity projectiles. Here again war decided emphatically, for in the World War it was conclusively shown that the decisive hits were those made by armor-piercing projectiles.

594. The principal function of armor is, therefore, to prevent, in so far as possible, the penetration of a projectile into a ship. But the "racking" effect cannot be neglected. This is at present, primarily a matter of securing—but the use of 16-inch, and even larger guns, with their projectiles of great weight; the demand for increased speed and consequent sacrifice in protection; and the probable obliquity of impact in action, are gradually forcing attention back to the "racking" or "smashing" attack.

595. The penetration of a pointed projectile into a homogeneous or simple plate was very accurately expressed, in the early days of armor, by various empirical formulas. The one which has survived the various developments, and is still the basis of armor calculation, is that of a Frenchman, J. deMarre.

This formula, as used in the last eighties, as applied to the penetration of cylindrical projectiles with ogival heads into plain wrought iron, is as follows:

$$e^{.65} = \frac{w^{.50}\,v}{\log^{-1} 2.9616\, d^{.75}},$$

or in the shape in which it is generally used:

$$\log V = 2.9616 + .75 \log d + .65 \log e - .50 \log w, \qquad \text{(A)}$$

in which

e = penetration in inches.
d = diameter of projectile in inches.
w = weight of projectile in pounds.
V = velocity of projectile in foot-seconds.

Problem I.—How far will a 10-inch 500-pound projectile penetrate into a wrought-iron plate at a striking velocity of 1772 f. s.?

Answer: 23.1 inches.

596. Subsequent to the adoption of nickel-steel armor, the formula was revised, and when applying to that material we use it in the following form:

$$\log V = 3.00945 + .75 \log d + .70 \log e - .50 \log w. \qquad \text{(B)}$$

Problem II.—How far will a 10-inch 500-pound projectile penetrate into a nickel-steel plate at a striking velocity of 1772 f. s.?

Answer: 15.77 inches.

Problem III.—What is the ratio between penetration in wrought iron and nickel-steel?

Answer: $\dfrac{\text{iron}}{\text{nickel-steel}} = 1.4647$ or $\dfrac{\text{nickel-steel}}{\text{iron}} = .6827.$

In nickel-steel armor, the projectile encounters a homogeneous material and therefore a more or less constant resistance. In face-hardened armor the projectile encounters media of varying hardness and strength, and its retardation follows laws which can be but imperfectly stated. For purposes of comparison, therefore, the limit of resistance of face-hardened plates is generally referred to a basis of penetration of nickel-steel.

597. Upon the introduction of face-hardened armor, therefore, the DeMarre formula was modified by introducing a coefficient of reduction (K), thus:

$$(K)\, e^{.70} = \frac{w^{.50}\,v}{\log^{-1} 3.00945\, d^{.75}},$$

or in the form in which it is used:

$$\log V = 3.00945 + .75 \log d + .70 \log e - .50 \log w + \log K. \qquad \text{(C)}$$

Problem IV.—Assuming K as 1.23 for a particular Class A plate, what would be the penetration of a 6-inch A. P. projectile weighing 105 pounds at 1836 f. s. striking velocity?

Answer: 7 inches.

598. The most useful and frequent application of the formula in this connection is, however, to determine the comparative value of plates. If we determine by test, the velocity at which a plate just resists penetration or just permits penetration by a particular projectile, we may consider the coefficient of reduction, mentioned above, as a *factor of performance,* and then, solve the equation to determine the factor of performance. The formula then becomes:

$$\log K = \log V - .75 \log d - .70 \log e + .50 \log w - 3.00945. \quad \text{(D)}$$

599. This formula is very useful for *normal* impacts, but like all empirical formula, it has its limitations. It is most accurate and useful at striking velocities between 1400 f. s. and 2000 f. s. and when the ratio between the diameter of the projectile and thickness of plate lies between 1.2 and 0.7; but it is liable to give erratic or misleading results when those limits are exceeded. And, in addition, *the formula assumes similarity of projectile quality and penetrative ability.*

Problem V.—Find the maximum factor of performance, or as it is generally expressed, the DeMarre coefficient, of a particular K. C., 12-inch plate.

Solution: Let us assume that our recent experience in testing armor has shown that the average DeMarre coefficient is about 1.16. Experience has also dictated that the DeMarre coefficient of a plate, can be most reliably and usefully determined when even caliber projectiles are used. (By even caliber, we mean that the caliber of the attacking gun and thickness of the plate are the same.) We therefore decide to use the 12-inch gun, with an 870-pound projectile, with which to secure our data.

Solve formula (C), for the conditions given, and decided upon, and we get 1463 f. s. We fire a shot at this velocity and learn that the projectile penetrated by a small margin, the amount of margin being approximated by its travel after penetration.

We fire a second shot at a velocity of 1400 f. s. and the projectile fails to penetrate, but from the looks of the hole it is certain that a slightly greater velocity would have caused penetration. We conclude that a velocity of 1420 f. s. would have just caused

penetration and using this figure we solve formula (D) and determine:

The maximum factor of performance of this plate is 1.12, or in other words, that its *limit of resistance* is represented by a DeMarre coefficient of 1.1165.

Problem VI.—A 14-inch Class A plate was attacked as follows:

First shot, 12-inch 870-pound projectile, at 1500 f. s. Penetration, 10 inches.

Second shot, similar projectile at 1545 f. s. Penetration, 13 inches.

Third shot, similar projectile at 1590 f. s. Penetration complete.

What DeMarre coefficient expresses the limit of resistance of plate?

Answer: About 1.108 at $V = 1570$ f. s.

Problem VII.—A 13-inch Harveyized nickel-steel plate was just defeated by a 10-inch 500-pound projectile, at a velocity of 1620 f. s.; while a 12-inch K. C. plate was just defeated by a similar projectile at a velocity of 1685 f. s. What is the relative value of the two plates?

Answer: Harvey plate is to Krupp plate as 1 is to 1.216.

Oblique Attack.

600. It will be accepted, without proof, that by inclining a plate to the line of fire its resisting power is enhanced. We may state this in two ways: first, as the angle of obliquity increases, with a given plate, the projectile will require a greater velocity to penetrate; or, as the angle of obliquity increases, there is a decrease in thickness of the plate necessary to defeat a given projectile, at a constant velocity.

The angle of obliquity is the angle between the line of fire and the normal to the face of the plate at the point of impact.

601. Many efforts have been made to express the relationships existing between normal penetration and oblique penetration, so far with but partial success.

Considerable experimentation has shown that while the ratio is obscure throughout the entire quadrant (normal to 0°) a much clearer relation is shown in each of the three sectors, from normal to 60°, from 60° to 30° and from 30° to 0°. That is to say, having determined the velocity necessary to defeat a plate at say 45°, the velocity to defeat the plate at angles of obliquity between 60° and

30° may be fairly accurately determined by applying a given ratio to that velocity. Or, having determined the defeating velocity of a plate, with given projectile, at 15°, one may predict, with reasonable accuracy, the defeating velocity with that projectile and plate at angles between normal and 30°.

602. It should be borne in mind that there is a real difference in the action of the plate and projectile in the three sectors mentioned above, the change from sector to sector being gradual.

However, in the most oblique sector, that from 30° to 0°, there is a decided difference from the other two for in this sector we are dealing with the glancing blow in most pronounced form. This difference has given rise to a specific class of armor, designed to care for this particular condition.

603. Experiments have indicated that the velocity necessary to defeat a plate varies about as the fourth power of the secant of the angle of obliquity.

Thus, if V = velocity which will just penetrate at normal and
V' = velocity which will just penetrate at an oblique impact of $\theta°$,

we have

$$V' = V \sec^4 \theta = \frac{V}{\cos^4 \theta}. \qquad \text{(E)}$$

604. This ratio can be reduced to figures, and when so used is generally referred to as an "angle multiplier." In order to plan an attack on a given plate we fix the normal velocity by the DeMarre formula (D) and apply the "angle multiplier" as determined by the above formula (E) to fix the velocity for the specified test.

In the sector from normal to 60° the ratio is more or less correct, while in the middle sector, from 60° to 30° it can be used as a basis of comparison.

Or, if we know with reasonable certainty the velocity necessary to effect penetration at a given angle on a particular plate and desire to calculate the velocity required to penetrate a plate of different thickness and equal ballistic resistance we would divide the velocity by the angle multiplier, then use the DeMarre formula (D) to calculate the relative velocities on the basis of normal impact, and finally secure our desired result by applying the "angle multiplier" to our calculated normal velocity.

605. These calculations can be facilitated by mathematically combining formulas (D) and (E), which gives us the following:

$$\log V = 3.00945 + .75 \log d + .70 \log c - .50 \log w + 4 \log \cos \theta, \quad (F)$$

where θ = angle of obliquity (between line of fire and normal).

In our discussions of Class A armor penetration and the use of the DeMarre formula, we have thus touched on two special factors: *the factor of performance for normal impact,* and the *angle multiplier* for oblique impact. In experimental work it is well to keep these two factors separate and distinct, and to plan and work out our problems so that the ratios between different plates are kept related to these two separate factors.

Class "B" or Deck Armor.

606. Prior to the introduction of compound or face-hardened armor all armor aboard ship was the same. It early became apparent that face-hardened armor was less effective against glancing impacts of considerable obliquity than was an equal weight of homogeneous armor. The advent of K. C. armor further strengthened this conviction. The development of a special armor to resist glancing blows dates, therefore, from the introduction of face-hardened armor. It is apparent, in the glancing blow, that a hard face is unnecessary, and that what is desired must be a combination of the highest strength and ductility, in order that the projectile may be gradually deflected. In other words, against this attack, we permit the armor to *give* under the blow, thereby spreading the effect, while the projectile slides along the trough it creates, thus further spreading the effect, and finally is completely deflected.

607. In a normal impact the blow is largely limited to a circular area with a diameter of about three calibers (see Plate VI), while in a glancing impact, at say 15°, the effect of the blow is taken on an area about three calibers wide and about four to five calibers long.

608. Armor to resist the glancing blow is now called "Class B Armor" in the American Navy, but it is also referred to as deck armor, horizontal armor, and special-treatment steel.

609. Nickel-steel continued to be used for horizontal armor for many years, and was accepted on physical properties as deter-

mined by tensile-pull specimens, until about 1909 when several developments took place. About that time the Carnegie Steel Company applied the newly developed nickel-chrome-vanadium alloy-steel to this armor and the change in composition and increased metallurgical skill enabled its resisting powers to be considerably increased. In that year the ballistic test of horizontal armor, for protective decks, turret tops, etc., began. These tests were at 81° obliquity.

610. About 1914 the use of vanadium was discontinued as it was found that more uniform plates could then be made.

At present, a nickel-chrome steel of approximately the same chemical composition as Class A armor is used, that is, carbon about .30 per cent, nickel about 3.85 per cent, and chrome about 1.85 per cent.

Class B armor, when less than 4 inches thick, is rolled in a mill instead of being forged, but above that thickness it is forged, as rolling thick plates is believed to work the plate less uniformly than forging, a condition which would, of course, tend to reduce ballistic resistance. Above 4 inches, if the plates are large, forging must be resorted to as there are no American rolling mills equipped to handle the required ingots.

The treatment is quite different from that of K. C. armor, for the desideratum is to secure great strength and ductility. Thus tensile test specimens frequently show an " ultimate strength " as high as 115,000 pounds per square inch with an " elongation " in two inches of 23 per cent and " reduction in area " of 65 per cent.

Ballistic Test.

611. Class B armor is handled in " groups " as is Class A armor, and each ballistic plate is subjected to the impact of a major-caliber projectile at angles of obliquity, depending on the thickness of the plate, from 80° up to about 55°.

Comparisons between plates and calculations as to suitability of plates to meet certain conditions may be approximated, for plates between approximately 4 inches and 9 inches, by the following mathematical methods. These are not applicable to plates less than 4 inches thick.

In the first plate the *resolved normal energy* is used to represent the force acting.

The energy of a projectile in foot-tons is represented by the expression

$$E=\tfrac{1}{2}Mv^2=\frac{wv^2}{2\times 32.16\times 2240},$$

while the resolved normal energy is represented by the expression

$$E'=\frac{wv^2\cos^2\theta}{144077}, \tag{G}$$

where

E = total energy in foot-tons.
E' = resolved normal energy in foot-tons.
w = weight of projectile in pounds.
V = velocity of projectile in foot-seconds.
θ = angle of obliquity (from normal).

As a rule the angle of attack, or the complement of the angle of obliquity, is taken in degrees as about four times the plate thickness in inches and the caliber of the projectile is taken as about two and a half times the plate thickness for 4-inch plates and twice the plate thickness for heavier plates.

Within the limits just stated the minimum thickness of plate to withstand attack may be expressed as follows:

$$E'=156e^2, \tag{G}$$

where

E' = resolved normal energy in foot-tons.
e = thickness of plate.

Combining the two expressions just given, we get

$$156e^2=\frac{wv^2\cos^2\theta}{144077},$$

or

$$\log V=\frac{7.35172+2\log e-\log w-2\log\cos\theta}{2}. \tag{H}$$

Using this formula, striking velocities may be calculated upon which to base a test, with a reasonable certainty that the limit of the plate may be approximately reached.

Problem VIII.—Determine the condition under which the first shot shall be fired to determine the limit of a $5\frac{1}{2}$-inch Class B plate.

Answer: Select, 14-inch gun, projectile weighing 1400 pounds.
Select, 68° as the angle of obliquity.
Then $V=1860.3$ f. s.

The above mathematical process is by no means thoroughly reliable, but it may be useful in handling comparative tests.

Armor Bolts and Securing.

612. References made heretofore in regard to armor butts, testing, and inclined armor, and a consideration of the enormous forces concerned on impact, point out the necessity of properly securing armor to the structure of the ship. Experiment only

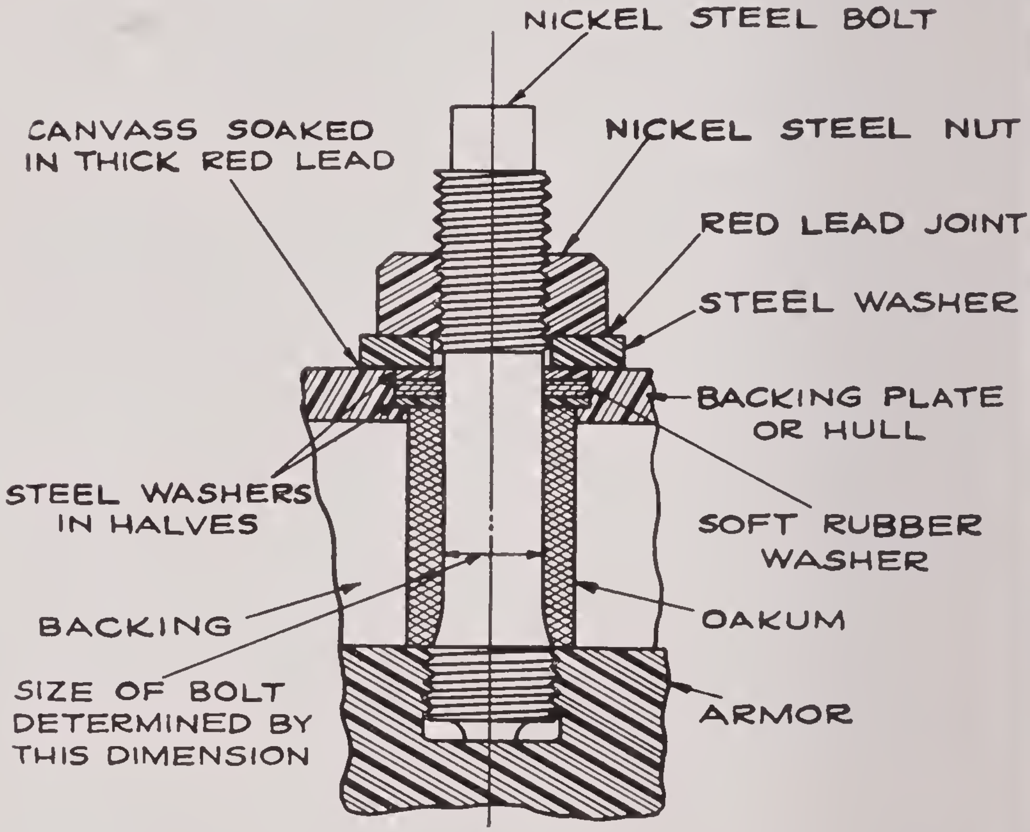


FIG. 107.—WATERTIGHT BOLT.

increases the importance to be attached to the subject. Many experiments have conclusively shown that all flexible mountings, such as steel springs, rubber buffers, etc., designed to absorb energy, cushion the plate, or extend the time interval in which the plate can act, are not only of no value, but are, on the contrary, a source of actual weakness.

Class A armor is bolted to the skin of the ship, or to her framing and bulkheads, with heavy bolts of special design called "armor bolts," the plates being placed against a backing of fitted timber or hydraulic cement. (See Fig. 107.)

FIG. 108.—BUTT, MAIN BELT, SHOWING KEY. EXTERNAL CLASS A ARMOR.

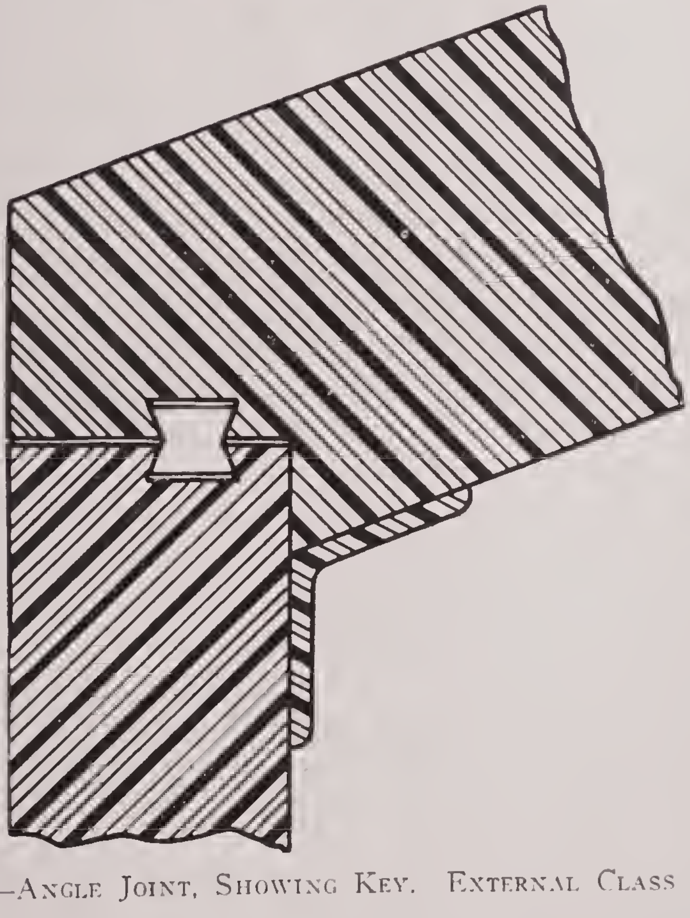


FIG. 109.—ANGLE JOINT, SHOWING KEY. EXTERNAL CLASS A ARMOR.

In addition to bolting, abutting edges are keyed together with a double tongue and groove key which is driven in endwise; and plates which meet at angles are rabbeted, or keyed. (See Figs. 108 and 109.)

Class A armor is seldom considered as a factor in the strength of the ship's structure.

Class B or deck armor, however, is generally worked into the structure, and in deck armor, except with the heaviest plates, is riveted in as in ordinary plating. The heaviest plates in decks and the tops of turrets and conning towers are secured with bolts, on the same general plan as are Class A plates. No backing is, of course, used.

613. Armor bolts are so spaced as to provide one bolt for every five square feet of surface, so far as the framing behind armor will permit, except in the case of 3-inch armor, for which one bolt is used for about six square feet of surface.

Armor bolts are made from good quality nickel steel (about 3.5 per cent nickel), the requirement being strength and ductility, for the bolt must be strong enough to hold the plate and should possess such ductility as will permit the plate to warp and spring under projectile impact without cracking.

Experiments and Conclusions.

614. The development of armor has only been secured by continual and costly experimentation, practically all of which has been productive of good.

Besides producing the armor which we use to-day, these experiments have demonstrated the following general principles:

(1) That, to be efficient, armor must be homogeneous as to mass, so as to concentrate the resistance.

(2) That armor should be rigidly attached to its supporting structure.

(3) That inclined armor, designed to deflect the projectile upon impact is, for purposes of protection, about equal to vertical armor of equal weight, when the angle of inclination is greater than the biting angle of the projectile; but when the angle of inclination is not greater than the biting angle, vertical armor of equal weight is more efficient. The introduction of the cap has not altered this principle.

Arrangement and Distribution of Armor.

615. Armor serves two purposes: First, protection for the water-tight integrity and interior mechanism of the vessel; and second, protection of the personnel.

This protection is afforded to as great an extent as possible by the armor belt, extending the whole length of the ship, the casemate armor, the protective deck, turrets, barbettes, gun shields, and conning towers.

The arrangement and distribution of armor on ships of various classes is described in works on naval construction, to which the reader is referred for details.

Light Armor.

616. During the World War, insistent demand resulted in the development of a third type of armor, generally called *light armor.* This type is used for the protection against small-arms fire, of the vital parts of soldiers' bodies, machine guns and light artillery, trains, automobiles, vital parts and personnel of aircraft, and its use is being extended to providing protection from aircraft attack, for the exposed personnel aboard ship.

In some of these uses, as for instance body armor, and aircraft armor, the greatest possible protection must be secured with the least weight, a condition imposed on all armor, in fact, but most accentuated in these uses. In this type of armor the metallurgist can use his utmost skill, for the mass is small. One might almost say that laboratory methods may be followed. This branch of the art is too young to permit of classification. So far no attempt has been made to face harden, for the thickness varies between $\frac{1}{16}$ of an inch for body armor, up to $\frac{1}{4}$ of an inch for aircraft armor, and then jumps up to about an inch for such heavy vehicles as tanks and trains.

Generally speaking, this armor resembles Class B armor, although many special and expensive alloy steels are being tried. We find the so-called, high-silicon, high-manganese, vanadium, zirconium, cobalt, chrome and nickel alloys in various proportions and combinations, and plates have been tested giving, with fair ductility, ultimate strengths per square inch as high as 250,000 pounds. One fact seems to stand out—*as desirable as is strength—good ductility is a necessity.*

CHAPTER XV.

PROJECTILES.

Form.

617. All projectiles, intended for use in cannon at long range, are similar in shape, irrespective of their size and the purpose for which they are intended. The shape now in current use is the result of an evolution which dates back to the first part of the fourteenth century, when cannon are first known to have been in existence in Europe. From that time until 1520 the principal projectiles were solid spherical stone balls and iron-headed darts. It is really astonishing to realize that guns of 25-inch caliber, firing a stone ball weighing about 700 pounds, were made as far back as about 1382!

While the casting of iron was known in the fourteenth century it required many years and experiments to apply the art to projectile manufacture. With solid spherical projectiles the sectional density can only be varied by varying the material in the projectile, and it is quite probable that the development of iron projectiles was retarded by the inability of the guns to stand such heavy projectiles without bursting. Gradually, however, it grew into use and in the early half of the sixteenth century cast iron became the principal material used in projectile manufacture. Shortly after this the hollow ball, or shell, was introduced.

Few developments of importance occurred thereafter until 1854, when the application of rifling to cannon began. That development had an immediate and pronounced effect on projectile design. The rotation of the projectile permitted its elongation; thereby securing increased range by reducing the head resistance for the same mass; increasing the accuracy of flight; increasing its penetrative ability; and increasing the mass of the projectile which a given gun could accommodate, or in more technical terms, the sectional density of the projectile.

Length.

618. At first projectiles were but slightly elongated, but each increase in the power of the gun and the efficiency of the rotative

mechanism was followed by a corresponding increase in the relative length of the projectile.

During the Spanish War our projectiles were between 2.5 and 3.0 calibers long, and during the World War their length had increased until 3.5 calibers was considered a medium length and 4.5 calibers was frequently and successfully used, with a few instances of even longer ones.

It is easily seen, without special mathematical demonstration, that as the length of the projectile is increased, its speed of rotation must be correspondingly increased. The problem of lengthening a projectile is, therefore, not a simple one.

Form of Forward End.

619. Early in this development many experiments were conducted to determine the proper shape for the extremities. The form adopted for the front end was that known as the *ogive,* which is generated by the revolution of the arc of a circle around a chord, the chord being the axis of the projectile, the versine of the arc being the semi-diameter of the projectile, and the sine of the arc being the length of the ogive. The shape of this ogive is generally expressed by stating its radius in terms of calibers. At the present time the majority of the U. S. Naval projectiles have ogivals of 7 calibers radius. Frequently the ogival shape is secured by the combination of several arcs of different radii. In recent years also, the ogival shape has been occasionally abandoned in favor of a conical shape, or partially conical shape, as that form lends itself with greater facility to mechanical processes.

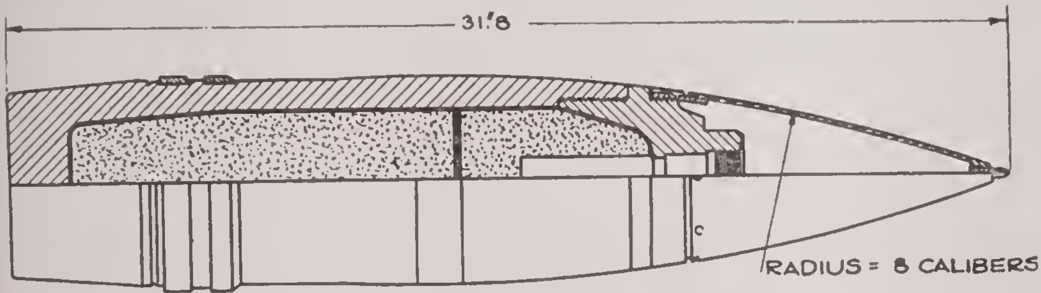
With proper rotation, it is desirable to keep the center of gravity of the projectile to the rear of, or in the immediate vicinity of, the center of form, particularly in long projectiles. As piercing projectiles require a blunt and solid nose for penetrative ability, the amount of metal in the forward end must be great. Also a fine forward form is conducive to long range. To reconcile these two opposing yet necessary qualities it has been advantageous to adopt light nose pieces, wind shields, or false ogives, all of which names are more or less synonymous. Several types of these are shown in the following sketches, and in the plate of projectile designs.

The following table shows, for a 6-inch projectile, the effect on the range of varying the radius of the ogive; the muzzle

velocity, angle of elevation, weight of the projectile, and form of rear being common for all shots.

Radius of ogive in calibers.	Length of projectile in calibers.	Effective range in yards.
2.5	3.00	9,083
5.0	3.37	10,549
6.0	3.50	10,921
7.0	3.62	11,285

The percentage of increased range, of the finer form over the blunter form, increases with the angle of elevation; that is to say, the improvement becomes greater as the range increases.



STREAM LINE GERMAN 6.8 INCH H. E. PROJECTILE
LENGTH = 4.7 CALIBERS

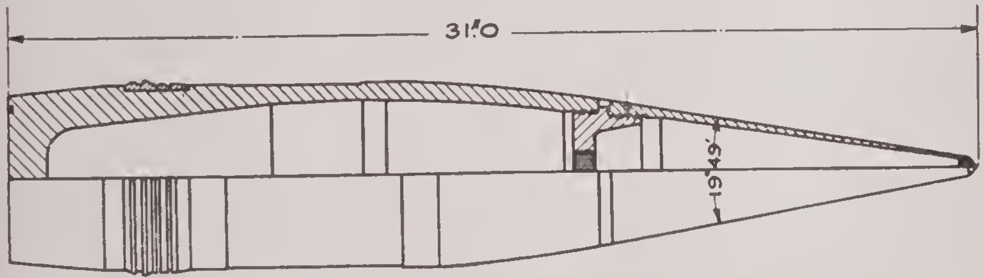


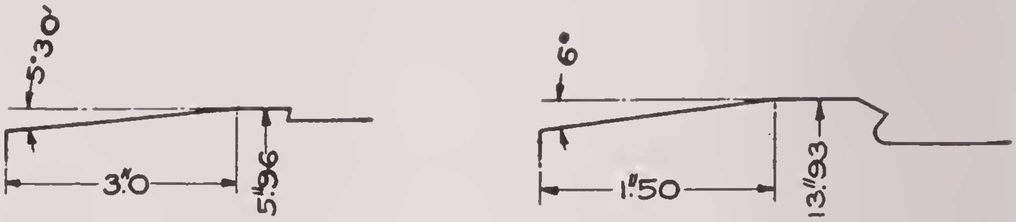
FIG. 110.—AMERICAN 6-INCH EXPERIMENTAL H. E. PROJECTILE. LENGTH = 5.2 CALIBERS.

Form of After End.

620. Variations in the shape of the rear end of the projectile have not been as prolific of beneficial results as might be expected from the preceding discussion of the forward end. All projectiles have the corner of the base turned to a small radius and for many years that shape was standard. Practically all U. S. Naval projectiles have this rounded corner, the radius varying from .375-inch for large projectiles down to a mere touch of the file on the corner of the small ones.

Frequent firings have, however, shown that increases in range can be secured by shaping the base to a finer form than a mere rounding of the corner. This scheme is generally referred to by naval ordnance engineers as *boat-tailing*, an expressive but peculiar term. But the deterrent fact is, that while comparatively small increases in range may be secured, they are generally accompanied by loss of accuracy! This is generally assumed to be caused by a flip or unequal side slap given to the rear of the projectile by the powder gases as they escape through the annular opening around its base before it has entirely cleared the muzzle.

It has finally been determined, however, that a high velocity (2500 to 3000 f. s.) projectile will give slight increase in range without loss of accuracy if the rear end is coned between 5° and 8° for a distance of from approximately .25 to .75 calibers, the angle of the cone between those limits depending on the velocity and form of ogive.



Base of 6-Inch CL. B. Projectile, 3000 F. S. Gun.

Base of 14-Inch CL. B. Projectile 3000 F. S. Gun.

FIG. 111.—BOAT-TAILING.

In cartridge-case projectiles another factor is added in connection with the form of the after end, for in such projectiles that portion must be kept cylindrical for a considerable length in order to provide a proper bearing for the cartridge case.

Form of Body.

621. Between the ends, whatever their shape and length, is the cylindrical portion or body of the projectile. At the after end of the body is the rotating band or bands, and at the forward end is the bourrelet. Between these two parts the diameter of the body is slightly reduced, in order to provide a generous clearance from the bore of the gun. It is the support and bearing provided by the band and bourrelet which steady the projectile in its travel through the gun and it is quite evident, therefore, that there must

be a reasonable distance between them, else too heavy a duty will be demanded of them in preventing wobbling. There is no fixed rule as to what this distance must be, but designers generally allow about one caliber for minor-caliber projectiles and increase the distance gradually up to about 1.4 calibers in major-caliber projectiles. We have touched on the benefits of stream lining the forward and after ends, and also on the limitations on lengthening the projectile as a whole. Considering these points in connection with the distance between band and bourrelet, we can at once appreciate the reason why projectile design is a compromise, and why advantage cannot be taken to the utmost of promising individual features.

Exterior Finish.

622. As a general rule projectiles are given, except on the bourrelet, only a rough machine finish, that is, one which, while smooth to the eye from a distance of say eight or ten feet, shows on closer inspection the marks of the turning tools. It is a popular fallacy that a smooth finish is conducive to accuracy. A very complete experimental firing was carried out some years ago in which a series of 14-inch target and armor-piercing projectiles were fired at a standard elevation, velocity and projectile weight; half of the projectiles being carefully ground and polished to a fine finish, while the other half were left with the usual finish. The difference in finish appeared to have negligible effect on the dispersion; in fact those projectiles with the rough or service finish gave a smaller dispersion than did those with the polish!

Weight.

623. Within reasonable limits projectiles can be given various weights for a given gun. The relation between weight of projectile and powder charge, muzzle velocity and pressure is a part of interior ballistics. The weight of all U. S. Naval projectiles follows a definite system of apportionment, which, stated in calibers, is as follows:

$$w=\frac{d^3}{2},$$

where

w=approximate weight of projectile in pounds.
d=caliber of gun in inches.

The weight of projectile per square inch of bore is called the *sectional density* of the projectile and is represented by the following expression:

$$S. D. = \frac{w}{A},$$

where

S. D. = sectional density.
w = weight of projectile in pounds.
A = area of bore, including grooves, in sq. in.

This figure has frequent application in gun and projectile design. It will be recognized as one of the factors in the empirical formula in the paragraph on Rotation (paragraph 633). The sectional density varies from 0.635 for a 1-pounder up to 10.44 for a 16-inch, averaging approximately .6 of the caliber.

The distribution of the weight in a projectile is a matter of considerable importance. As a general rule, the center of gravity should be in the longitudinal axis and close to or abaft the center of form. Slight variations in the location of the center of gravity, with respect to the center of form, have negligible effect on the dispersion. For instance, the center of gravity of an 8-inch projectile was moved back and forth .5 inch, in a series of firings, without showing any appreciable effect on the dispersion. And similarly, the center of gravity of a series of 12-inch projectiles was moved to one side of the longitudinal axis, .013 inch, .039 inch, and .052 inch, respectively, without producing appreciable effect in the range or dispersion.

The Bourrelet.

624. The "bourrelet" (see Plate I) is, as was stated previously, the forward bearing, so to speak, of the projectile. Its surface is generally ground to a fine finish in order to reduce friction and to prevent wear of the lands of the gun. This bearing surface is generally about one-sixth caliber in width, that is, longitudinally with the projectile. Some few small projectiles have no real bourrelet, the entire body of the projectile forward of the band replacing it.

The bore of a gun becomes "coppered" after repeated firing, with a fine deposit of copper from the projectiles' rotating band. And frequently, also, the liner in a gun becomes slightly crumpled

or ridged, after repeated firing, particularly in wake of internal shoulders. (See paragraph 341.) A certain clearance must, therefore, be provided between the bourrelet and the lands. The standard U. S. Navy practice is to make the bourrelet diameter .015 inches smaller than the bore of the gun. A minus manufacturing tolerance is added to this diameter of another .015 inch, so that the average clearance is about .012 inches. Clearances of .05 inches have practically no effect on the dispersion, but it is reasonable to assume that unnecessary clearance can have at least no beneficial action, and may have an injurious effect on the lands, due to the blows of possible wobbling. It is quite apparent, also, that the less the clearance, the more accurate will be the initial direction of the trajectory.

In a few instances a centering band of copper replaces the bourrelet, but as yet this system has not had wide application. It is generally conceded to be inapplicable to armor-piercing projectiles, as the "score" would weaken the projectile at a vital locality.

Rifling.

625. The rifling cut in the bore of a gun consists of spiral grooves whose function is to engrave the rotating band immediately after the projectile begins its motion and then to cause rotation as the motion continues. For the engraving of the band the rifling is slightly coned at the origin, to fit the conical part of the band, and this is called the *band slope*.

Most U. S. Naval guns now in service contain rifling in which the grooves occupy, at the muzzle, about half the circumference, or in other words, lands and grooves are of about equal width. This practice is by no means universal, and there are frequent instances where the grooves are as much as twice the width of the lands. It will be noted that the ratio between width of lands and grooves has been qualified by specifying *at the muzzle*. The reason is that grooves are generally tapered in width, being wider at the origin of rifling than at the muzzle. In other words, the land is wider at the muzzle than at the origin of rifling; this widening is called the "increased forcing" of the projectile. This is done to assist in maintaining the gas seal. It is easily appreciated that the maximum wear of band occurs against the driving edge of the land. If the land widens as the projectile moves down

the bore, the increase in width may compensate for the wear. This question is intimately connected with the question of "increasing" and "uniform" twist, which is discussed later. It will be apparent that if the twist is variable, or increasing, the change of angularity of the land with respect to the band may have about the same effect on the gas seal as will the widening of the land. Many guns in service of 5-inch caliber and above, with both uniform and increasing twist, have lands of increasing width. This increase has gone as high as .40 inch in 1000 inches of length. At present it is the practice to maintain a constant ratio between width of land and groove in increasing twist guns, and to widen the land at the rate of .08 inch per 1000 inches in uniform twist guns.

Where the bottoms of the grooves are concentric with the bore and their edges are approximately radial, the rifling is said to be "*plain-section*" and is usually spoken of as "ribbed" rifling. But where the driving side of the groove is the arc of a circle of small radius and the trailing side is the arc of a circle of large radius, or a straight line at a large angle to the radius of the bore, the rifling is said to be "*hook-section*" or simply "hooked."

Sharp corners at the bottom of grooves are considered as injurious, the theory being that they facilitate the formation of heat cracks and accelerate erosion. Liberal fillets are, therefore, provided at the bottom of grooves. Sharp corners at the corners of the lands are also eliminated but with fillets of smaller radius.

Hooked rifling has been extensively used in the U. S. Navy and guns of various types and calibers up to 14-inch will be found in service. In recent years, however, no guns of 14-inch or above have been designed with hooked rifling.

626. The depth of the groove depends on several factors; the muzzle velocity, pressure, width of band, type of rifling, sectional density of projectile, and caliber of the gun, all requiring due consideration. In a gun designed for high pressures, or high rotation of projectile, the driving area must be large and this can only be secured by deepening the groove or widening the band. Very deep grooves are injurious as such a form is considered to be conducive to the formation of heat cracks and the acceleration of erosion. No simple rule can be given, therefore, to govern the depth of grooves, although, speaking generally, the depth will lie between ½ and 1 per cent of the caliber.

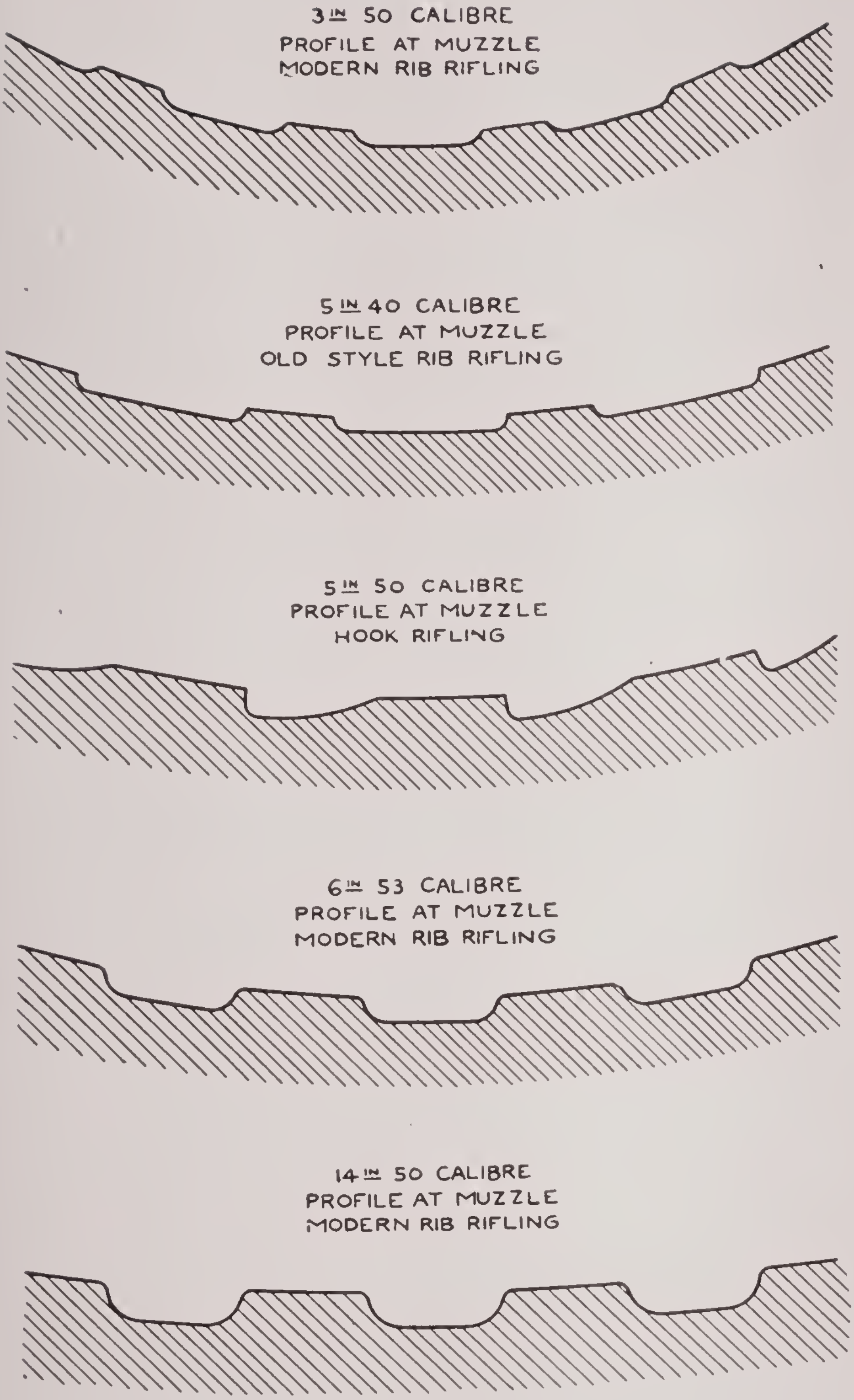

3IN 50 CALIBRE
PROFILE AT MUZZLE
MODERN RIB RIFLING
5IN 40 CALIBRE
PROFILE AT MUZZLE
OLD STYLE RIB RIFLING
5IN 50 CALIBRE
PROFILE AT MUZZLE
HOOK RIFLING
6IN 53 CALIBRE
PROFILE AT MUZZLE
MODERN RIB RIFLING
14IN 50 CALIBRE
PROFILE AT MUZZLE
MODERN RIB RIFLING

FIG. 111A.

627. As is the case with the depth of grooves, no fixed rule can be given for their number. The number of grooves is generally expressed as a function of the caliber in inches, thus 7.5 grooves per caliber would give 30 grooves for a 4-inch gun. There are certain guns of almost every caliber in the U. S. Navy where the grooves number six times the caliber and that number not only expresses the average past practice, *but is also the present practice.* In small guns the factor is increased and has gone as high as 10. Many old guns in our service from 5-inch to 13-inch, inclusive, were, however, as low as four grooves per inch of caliber. Some of the most successful ordnance engineers in Europe are now using about 7.5 grooves per inch of caliber.

628. The amount of "twist" is generally expressed in America by the number of calibers traveled during one revolution of the projectile, as for instance, *one turn in 25 calibers.* In continental Europe, the twist is frequently expressed by the angle between the groove and a plane passing through the axis of the bore. The relation between these two quantities may be expressed as follows:

$$\tan \theta = \frac{\pi}{\text{calibers for 1 turn}} \quad \text{where } \theta = \text{angle of twist.}$$

As the tangent of small angles is approximately equal to the angle in radians, this relation can be approximated by the thumb rule of dividing 180 by the number of calibers required for one turn to secure the angularity. Thus a twist of 1 in 25 is approximately 7°. The twist of rifling is also frequently called "*pitch.*"

629. The rotation of a projectile is seldom expressed in R. P. M., but it is interesting to calculate it in order to compare it with that of other rotating machinery, as follows:

$$\text{R. P. M.} = \frac{(\text{Muzzle velocity in f. s.}) \times 720}{(\text{Twist in cal. per rev.}) \times \text{caliber in inches}}$$

Thus, a 6-inch gun, at 2800 f. s., rifled 1 in 30, gives its projectile 11,200 R. P. M.

630. Twist can be either *uniform* or *increasing.* In "*uniform twist*" the grooves follow a uniform spiral, or, in other words, are inclined at a constant angle to the axis of the bore. In "*increasing twist*" the grooves possess little or no twist at the origin, but gradually increase the twist toward the muzzle. When the rifling begins with *O* twist and *uniformly increases* the developed curve

is a parabola, and such a twist is generally called "parabolic twist." Increasing twist may be a combination of various uniform twists, connected by parabolic or easy curves. All increasing twists in U. S. naval guns are semi-cubic parabolas. Fig. 107 shows the developed curves of three forms of rifling—*A*, being uniform twist; *B*, a parabolic twist; and *C*, a combination, 1 to 50 to 1 in 32 twist, the final twist in all three being the same.

631. When rifling was first applied to cannon design, it was without exception made uniform. At that time slow-burning powders as we now know them were unknown, and in uniform

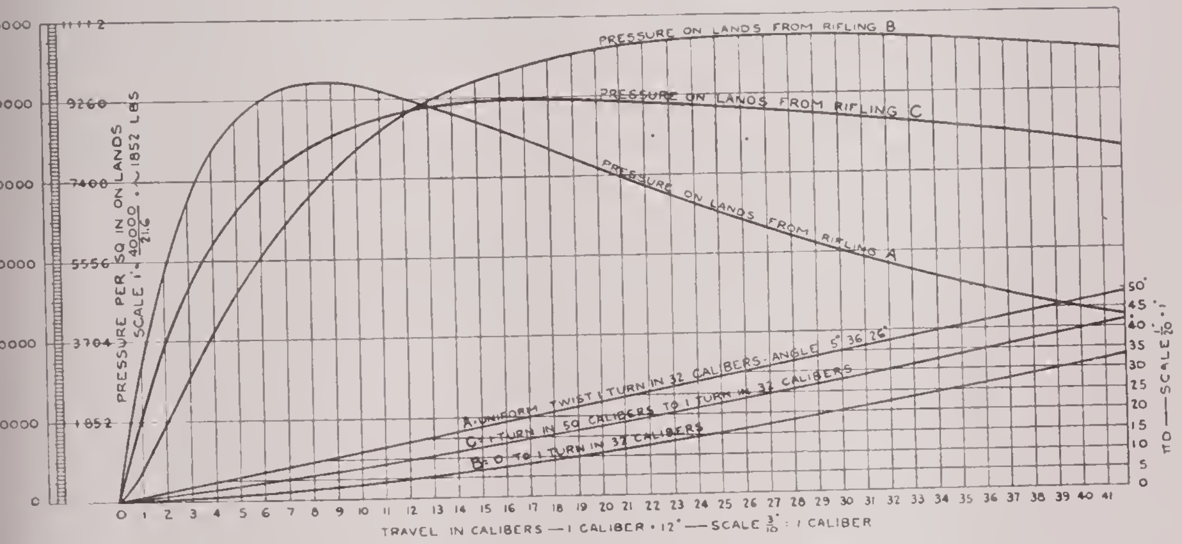


FIG. 112.—RIFLE CURVES FOR 12-INCH GUN MARK VII, MOD. 1. M. V. 2900 F. S. WEIGHT OF PROJECTILE 870 LBS.

pitch the instant at which maximum torque is applied to the projectile coincides with the instant of maximum chamber pressure. These two factors imposed a very sudden and large torque early in the travel. It is quite evident, therefore, that under these conditions, a reduction in the initial twist effected a reduction in the maximum torque. Also, a delay in the instant of maximum torque results in a slight slowing down of the powder. These influences lead to the introduction and development of increasing twist, and combinations of increasing and uniform twist.

Most of the guns now in service have increasing twist, the rifling beginning with zero twist and ending with 1 in 25 twist, although the larger guns now in service begin with a twist between 1 in 40 and 1 in 50.

632. Progress in gun and ammunition design is, however, gradually diminishing, if it has not already eliminated, the advantages of increasing twist over uniform twist. Guns are longer, pressures higher, power greater, and muzzle velocity higher; while powder is being made to burn slower and increase the muzzle pressure. As applied to a modern high-powered gun, the relative merits of the two systems may be summarized as follows:

INCREASING TWIST.

1. Reduces the maximum torque on the projectile.

2. Is considered to reduce erosion, by reducing the work on the lands where the erosion is greatest, that is, near the origin of rifling.

3. Necessitates as narrow a band as possible, and consequently one band.

4. Results in considerable shearing of the band, especially in long high-powered guns, with wide bands on the projectile.

5. Probably causes additional copper deposit in the middle third of the bore.

UNIFORM PITCH.

1. Permits a band of any width or as many bands as desired.

2. Reduces the torsional strain on the muzzle of the gun.

3. Consumes less energy in moving the projectile through the bore, and hence delivers a greater muzzle energy.

4. Gives a clean-cut engraving to the rotating band.

633. The riflings of most American, and many European cannon, were tabulated by Mr. C. F. Jeansen, of the Bureau of Ordnance, who deduced therefrom the following empirical formula:

$$T = \frac{v}{d} \times \frac{w}{A} \times \frac{1}{K}.$$

Where
T = twist in calibers at muzzle.
v = muzzle velocity in f. s.
d = diameter of bore in feet.
w = weight of projectile in pounds.
A = area of bore in sq. in. (including grooves).
K = factor of reduction.

The application of this formula to the tabulation of guns gives an average value for K of 640. Such guns as have shown the

most satisfactory accuracy and life give a value very close to this figure, and it has been suggested therefore that the value of (640 ± 150) be given for future design.

This formula, while useful, is not capable of mathematical demonstration. Applying it to a 6-inch 2800 f. s. gun, with 105-pound projectile, we would get a final twist of about 1 in 33.5 calibers.

The Rotating Band.*

634. The rotating band has three specific functions—to seal the bore, to steady and center the rear end of the projectile, and to rotate the projectile. It is also utilized to prevent over-ramming in worn guns and to hold the projectile in place during loading and elevating for firing. In addition to these functions the band has considerable effect on the range, dispersion, muzzle velocity and life of the gun.

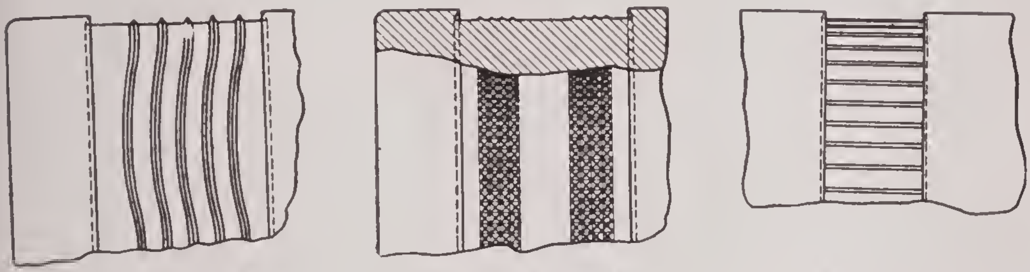


FIG. 113.—METHODS OF PREVENTING SLIPPING OF ROTATING BAND.

Rotating bands are made of commercially pure copper for all minor and medium caliber projectiles, and of cupro-nickel alloy containing 2.5 per cent nickel for major-caliber projectiles, the nickel being added to secure greater strength.

As a general rule rotating bands are about $\frac{1}{3}$ caliber in width. In some instances, particularly abroad, the width of a band is kept down to a maximum of about 1.5 to 2.0 inches, and where a greater strength is necessary two separate bands, separated by a short distance, are provided. This system has considerable merit.

The band is secured in a *score* cut in the projectile body, there being a dovetail on each edge to assist in overcoming centrifugal force, and either waved ridges, longitudinal nicks, or knurling in the bottom of the score to insure against slipping during acceleration. The band is made as a ring of slightly greater internal

* Rotating Bands are also called "Forcing Bands."

diameter than that of the body and is slipped over the score, while hot, and pressed radially into place in a powerful hydraulic press called a "banding press." (Fig. 114.)

635. The forward edge of the band is slightly conical and fits into a correspondingly coned seat at the origin of rifling.

The central portion of the band is generally cylindrical and of a slightly greater diameter than the diameter of the bore including grooves. An expression often used to obtain the diameter is $D=C+2p+.02$ where C is the caliber of the gun, and p the depth of the grooves.

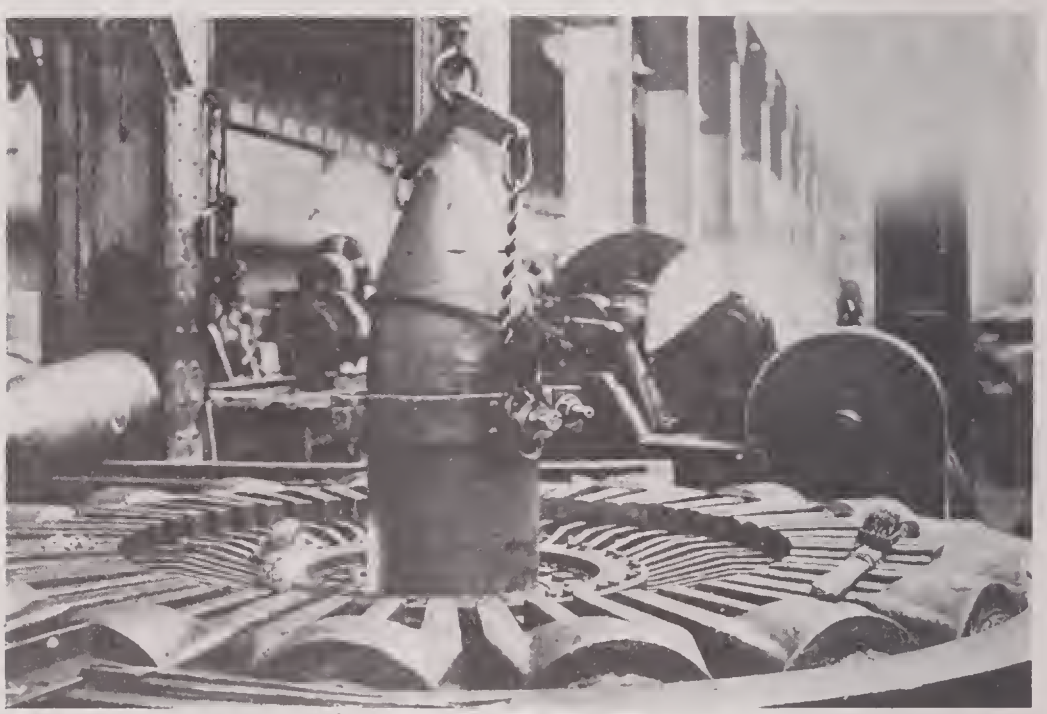


FIG. 114.—BANDING PRESS.

It will be observed (Fig. 115) that on the rear part of practically all bands is a raised lip. This lip serves the purpose of insuring a good gas check and at the same time, because of its considerably greater diameter, preventing over-ramming in a worn or eroded gun.

When the gun is fired and the pressure rises, the projectile is forced into the rifling which then *engraves* the band to fit the contour of the bore, and the revolution of the projectile ensues. It is easily seen that the driving face of the lands should be radial so that the rotative force will be applied normally.

636. With uniform twist rifling the lands in the bore present a constant angle to the band. After the first engraving, therefore,

there is no further flow to the metal in the bands other than the slight drag and wear due to friction. With parabolic or increasing twist rifling, however, the lands in the bore present a constantly increasing angle to the band. In this case, therefore,

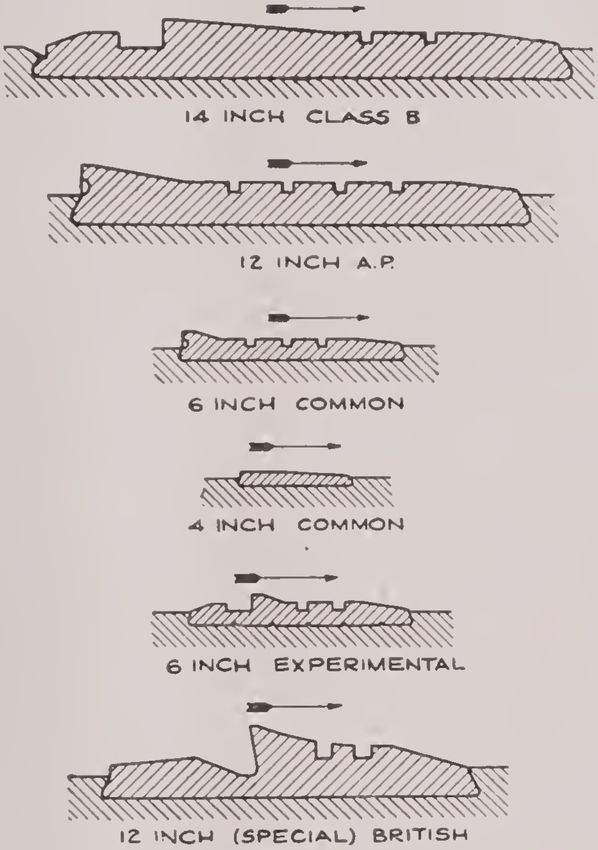


FIG. 115.

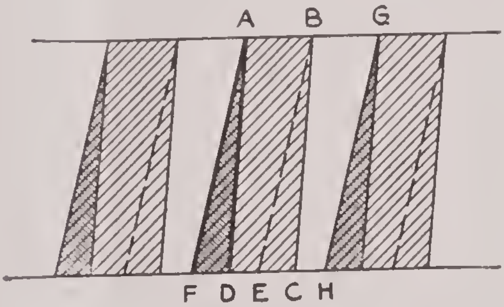


FIG. 116.

there is a continual flow of metal due to the changing pitch of the thread. This condition is shown in Fig. 116, which diagrammatically represents the parts of an engraved band covering three grooves in the rifling.

The shaded portions represent the imprint of the land on the band when the projectile leaves the muzzle, *A D* being the initial driving edge with the smaller twist and *A F* being the final driving edge with the larger twist. During the travel of the projectile down the bore the imprint of the land has been shifted from *A B C D* to *A B E F*. It is evident, therefore, that the copper under *A D F* has been removed during the travel and that the projection on the band which remains in the groove of the gun is covered by *B G H C*. This loss of copper is exhibited by increased friction in the bore, some authorities stating that increasing twist creates $2\frac{1}{2}$ times as much frictional loss of energy as does uniform twist.

637. In order to insure a tight joint, especially in eroded guns, the diameter of the cylindrical portion of the band is generally a few thousandths of an inch greater than the diameter of the bore across grooves. It is clearly evident, however, that any excess metal in the band will be pressed or wiped back toward the base of the projectile, this being more pronounced in wake of the lands. Should this excess metal be of sufficient quantity it will form a scalloped skirt extending abaft the band score. Now at the instant that this skirt clears the muzzle there will be a rush of gas past it, which, aided possibly by centrifugal force, may turn this skirt out radially at a considerable angle. This is called *fringing* and a pronounced fringe can have a material effect on the range and dispersion, the effect being greatest on minor and medium caliber projectiles.

The successful design must not only provide sufficient metal in the band to secure the desired performance, but must also insure against fringing. Grooves or " cannelures " are placed in the middle portion of large bands, for the purpose of allowing space for this excess copper and a large groove is also frequently provided abaft the lip to take this excess copper.

638. It is important to fix upon the position of the forcing band (rotating band) and the precise distance from the rear edge of the band to the base of the projectile, and is even more important, when the caliber is smaller, than the forcing and indentation of the grooves. The resultant of pressure on the base of the projectile is seldom axial with the bore; it is usually inclined to this axis, and does not pass through the center of the base. This eccentric and oblique action of the resultant gives rise to a couple, which tends to

rotate the projectile about one of the diameters of the forcing-band, and to produce jolting or beating along the walls of the gun (*"ballottement"*); the projectile leaves the piece with perturbations, which do not allow an efficient overcoming of the air resistance, and which produce a sensible diminution of range and accuracy of fire. Experiments have shown that there is one particular position of the band in which this couple, to which the projectile owes its perturbations, is reduced to a minimum, and to which, as a part of other conditions, the maximum range and best stability of flight correspond. In this position the rear edge of band is one inch from the base of the projectile.

Stability and Flight.

639. The mathematical demonstration of the stability of projectiles is not only without the scope of this work, but is by no means in a settled condition. The difficulty lies in our inability to determine the precise nature of the forces acting on the projectile in flight.

The gyroscopic effect of the rotation of the projectile is to stabilize or hold its axis in a fixed position in space. Were this action to remain unaffected by external force, the projectile would travel with its axis always at the same angle with the horizontal, and would strike with its axis at an angle to its direction of travel equal to the sum of the angles of departure and fall. Experiments have shown, however, that the axis of a projectile, having a smooth flight, is practically in the trajectory at the point of fall, and presumably therefore throughout its entire flight. The effect of atmospheric resistance is, therefore, not only to slow down its rotation and translation, but to form with the gyroscopic force, a "couple" which effects a continual *tipping down* of the forward end of its longitudinal axis. It is quite evident, therefore, that there must be a specific rotational speed most suited, for a given projectile, to a particular velocity.

The balance of this couple is an important feature in any discussion of rotation. If the resultant of the couple created by the atmospheric resistance preponderates, the projectile ceases to be stable, and tumbles. If the gyroscopic force preponderates the projectile refuses to tip and a complex series of forces immediately ensues which causes the projectile to corkscrew. The balance is

not restricted to a precise relation, but allows certain limits between which the flight is smooth and stable.

640. A study of the plotted trajectory of any projectile will show that its curvature is small during the early stages and final stages but is large during the middle stage, the maximum curvature being in the immediate vicinity of the vertex. That is to say, therefore, that the yielding or tipping of the axis must accomplish a much greater and more rapid change in direction while in the neighborhood of the vertex than in any other position of the trajectory.

It is generally accepted that the atmosphere has a greater retarding effect on the translational velocity, than on the rotational velocity. This being true, the ratio between translational energy and rotational energy continually decreases during flight; or in other words, the gyroscopic force continually increases in relative proportion, or again, a projectile which starts with a minimum margin of rotation gradually increases that margin.

If might be mentioned parenthetically that experiments have been recently undertaken, principally abroad, to put vanes on the ogive which will increase the rotational retardation and tend, therefore, to preserve the initial ratio between the rotational and translational velocities.

Now, from the above it is evident that the performance of the projectile *at the vertex* is the essential feature of a study of its rotation. It should be noted that with low angles of elevation, or flat trajectories, the curvature at the vertex is so slight as to require no special consideration, but as the elevation increases the curvature becomes greater until at angles of elevation of about 60° or greater the curvature at the vertex is abrupt, and at such angles a projectile will not dip sufficiently, but may either tumble or descend base first. We may now consider the phenomena which enable us to fix the proper rotation to give a certain projectile.

641. If a projectile is launched with insufficient rotation, the gyroscopic force is overcome by the resultant of the external forces and the projectile " tumbles " or goes end over end. This is discernible through pronounced and intermittent sound developed during early flight and excessive dispersion. It is also determined by firing the projectile through cardboard screens. In service such phenomena are exhibited in old guns with such badly

eroded bores that the rifling is unable to impart the designed rotation to the projectile. Projectiles with insufficient rotation have been known to turn sideways within 100 feet of the gun.

If a projectile is launched with excessive rotation, there is little early indication of difficulty, other than excessive drift, and little effect on short ranges with flat trajectories. As the elevation is increased, however, and vertices are reached which require rapid change in inclination or dipping, the gyroscopic forces preponderate, a corkscrew path results, and the visible effect is excessive dispersion.

In other words, insufficient rotation is connected with short range phenomena, while excessive rotation is, speaking broadly, connected with long range phenomena.

Under-Water Attack.

642. When an ogival-headed projectile, traveling in air, strikes water, it deviates from its trajectory in a violent and uncertain manner. At small angles of fall it tips up, runs parallel with the surface for a short distance and then, if it still has sufficient velocity, emerges and again takes to the air. This is called a *ricochet*. At greater angles of fall it is liable to deviate in any irregular direction.

The desirability of the attack of submarines by gun fire from surface or aircraft has resulted in the development of projectiles which maintain their trajectory, upon entering water, with reasonable accuracy. In these projectiles the ogival form is abandoned and a square head is substituted. Such projectiles are called, in our navy, "Flat Nose" projectiles and elsewhere are referred to as "diving shell." (Plate I, Figs. 1 and 2.)

The retardation of the translational velocity of these projectiles in both air and water is excessive, but such a sacrifice has to be made in order to secure accuracy upon and after water impact. Interesting proposals have been made to fit flat-nose projectiles with thin wind shields or false ogives which will collapse and be wrenched adrift upon impact with water, thereby preserving both good flight in the air and under-water accuracy.

Classification.

643. The impact damage which a projectile itself does is entirely secondary to that which results from its burst. The design

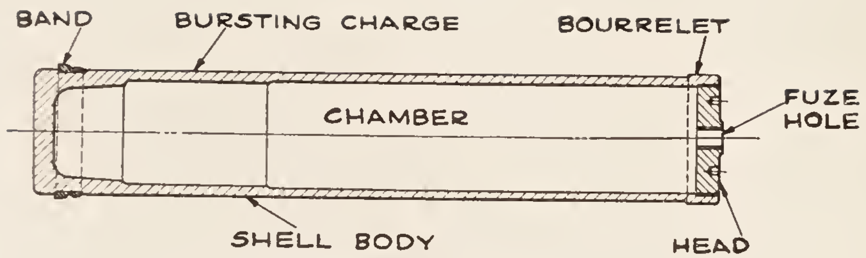
of most projectiles is based primarily on using the projectile as a vehicle with which to carry a quantity of explosive into a ship and secondarily to provide missiles with which to carry the force of the explosion.

Where the projectile must meet heavy face-hardened armor the result is a massive piece of steel with a heavy head, thick walls and a small cavity, called an *armor-piercing projectile.* In such projectiles the weight of the bursting charge (high explosive) varies between 2.1 per cent to 2.6 per cent of the total weight of the projectile. If the size of the charge is increased the projectile is unequal to matching even caliber plate at battle ranges and angles of fall, while if the size of the charge is reduced the fragmentation of the projectile on burst is not efficient. (Plate I, Fig. 3.)

Where the projectile may encounter only a combination of light side plating, bulkheads, and decks, the cavity can be somewhat enlarged, and the design is called a *common projectile.* In such projectiles the charge represents, for medium and major calibers, about 6.0 per cent of the total weight, and for sizes below 6-inch the percentage falls to about 3.0 per cent to 3.5 per cent. (Plate I, Fig. 4.)

And finally, where the steel envelope is made only sufficiently strong to stand the shock of firing or "set-back" (see Art. 691), in the gun, the cavity is as large as possible, the design is called, in the American Navy, a *Class B projectile,* and by ordnance engineers in general a *high-capacity* projectile. (Plate I, Figs. 1, 2, 5 and 6). Such projectiles are fitted to burst on impact. It should be noted that the strength of the walls of such projectiles is fixed by the set-back; in consequence the lower the muzzle velocity of the gun, the greater will be the relative size of the cavity, for a given weight of projectile. In high-velocity (3000 f. s.) ogival-headed projectiles, the weight of charge can be carried as high as 10 per cent to 12 per cent of the total projectile weight, and in low-velocity (1000 f. s.) flat-nose projectiles, the weight of charge can be increased as high as about 25 per cent of the total projectile weight.

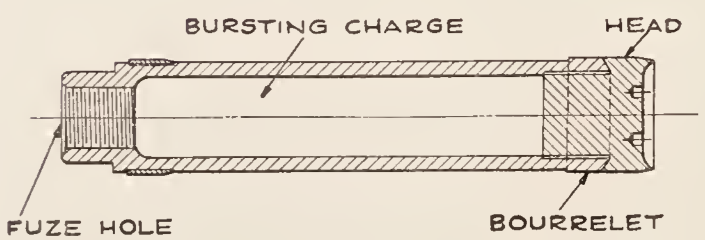
There is another class which finds favor in certain countries, called semi-armor-piercers. These projectiles are between the armor piercer and the common, and are designed to match a half-caliber plate at battle ranges and angles of fall. They carry about 3.5 per cent to 4.0 per cent of their weight in the bursting charge.



8 IN. CL. B PROJECTILE
FLAT NOSED

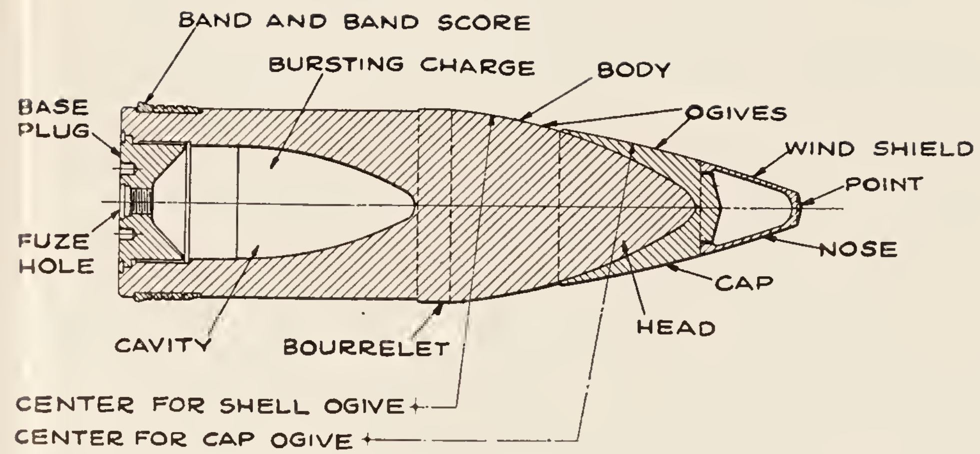
$\frac{\text{WEIGHT OF CHARGE}}{\text{WEIGHT OF PROJECTILE}} = 26.2\%$

Fig. 1.



9 PDR. PROJECTILE
CUP-NOSED

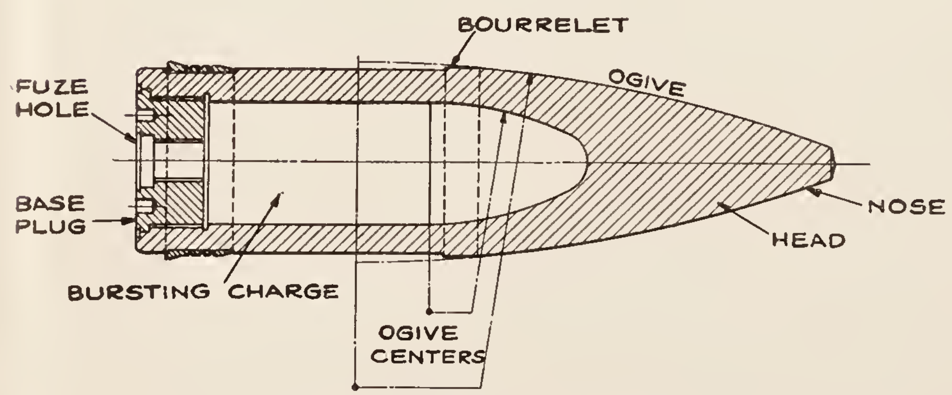
Fig. 2.



12 IN A.-P. PROJECTILE

$\frac{\text{WEIGHT OF CHARGE}}{\text{WEIGHT OF PROJECTILE}} = 2.6\%$

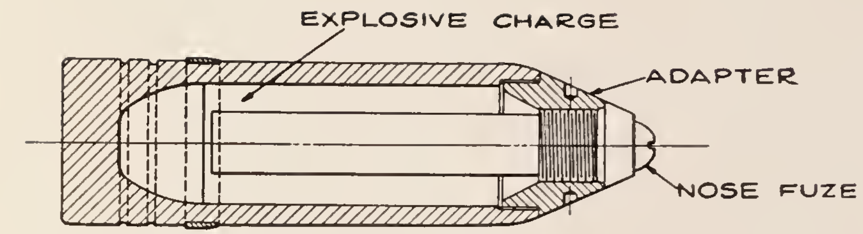
Fig. 3.



6 IN. PROJECTILE (COMMON)

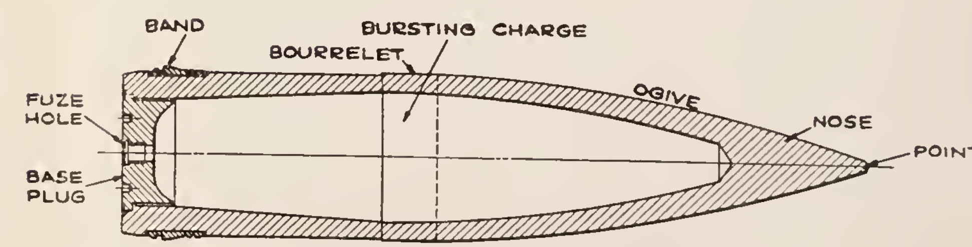
$\frac{\text{WEIGHT OF CHARGE}}{\text{WEIGHT OF PROJECTILE}} = 6.09\%$

Fig. 4.



3 IN. HIGH CAPACITY SHELL

Fig. 5.



14 IN. CL. B PROJECTILE

$\frac{\text{WEIGHT OF CHARGE}}{\text{WEIGHT OF PROJECTILE}} = 11.5\%$

Fig. 6.

EXAMPLES OF PROJECTILES.

In addition to the three above mentioned general classes, are other special projectiles such as shrapnel, illuminating projectiles or star shell, smoke and gas shell.

Let us now examine these projectiles in detail.

The Armor-Piercing Projectile.

644. The predominating school of thought during the Civil War, in connection with the attack of armor, was to smash in the armored side of a vessel with solid shot and spread splinters from the broken projectile, plate and backing, over the back areas; rather than to penetrate the armor and burst the projectile in the rear. As noted in Art. 593, this theory had a short life and the introduction of rifling finished it. It was a long time, however, before the use of the solid shot was abandoned. As late as about 1895 solid shot were made for armor penetration only. There are, however, frequent revivals of variations of the "smashing effect." The development of high explosives led to the advancement of the theory that a large quantity exploded against the armored side of a vessel would cave in the armor and plating and completely destroy that part of the vessel in the general neighborhood of the impact. Costly and elaborate experiments, carried out in this country during the past 10 years, have conclusively shown that high-capacity, high-explosive projectiles detonating on the armored side of a vessel have no appreciable effect on the armor and negligible effect on the adjacent ship's structure. Furthermore, the engagements of the World War show beyond doubt that, while major-caliber Class B or common projectiles may produce great havoc in upper works and unarmored localities, modern armored vessels are almost immune to disablement by other than armor-piercing projectiles of the finest quality.

The first development in armor piercers, after the ordinary cast-iron shot, was the Palliser chilled-iron projectile, which was introduced in England in 1866. This projectile was an iron casting, cast point down, the lower part of the mold being an iron chill while the upper part was sand. These and similar projectiles were used up until about the introduction of steel armor. It is quite probable that cheapness was an important factor in their continued use, for in 1862 Whitworth patented a case-hardened heat-treated mild-steel projectile with a hard head and soft base.

Wrought iron was frequently tried, but due to its inherent ductility never made any headway. In 1878 extensive trials at Shoeburyness showed that the Whitworth projectile had surpassed all other makes in penetrative qualities.

But about this time the firm of Jacob Holtzer et Cie. in France produced a forged high-carbon, nickel-chrome, crucible steel armor piercer which, in spite of the efforts of rival manufacturers to duplicate, remained the most efficient projectile in existence for many years. In 1886 the Navy Department secured a few Holtzer projectiles from St. Chamond. These contained about 1.80 per cent chrome and .80 per cent carbon. Shortly after this the Holtzer and rival processes were imported into America.

645. The next real development in armor piercers was the introduction of the *cap*. In 1878 a comparative test was made in Europe of the effects of projectiles against the face and back of a compound plate. The same projectile which smashed on the face completely penetrated when the plate was reversed. A thin wrought-iron plate was then placed in front of the hard face and this was found to materially increase penetration. And finally a wrought-iron jacket was placed over the point of the shot which gave the same result of increased penetration. It appears to be authentically established that in 1883 Colonel Inglis of the English Ordnance Committee devised the first soft-steel caps. In 1896 Mr. I. G. Johnson submitted some 6-inch solid fluid-compressed steel shot to the Navy Department on the noses of which he had placed a small cylindrical mild-steel cap. An important feature of these caps was that an annular space was left between the point of the projectile and the rear portion of the interior surface of the cap, which was filled with graphite. These projectiles completely penetrated a 7-inch Harvey plate when striking at 2100 f. s., while similar uncapped projectiles at the same striking velocity smashed on the plate. Shortly after this, caps were placed on all American armor piercers, but the graphite feature was later abandoned. A few years ago the cap was improved by making it of high-carbon chrome steel and hardening it decrementally, although the idea had been patented in 1896.

Since the introduction of forged high-carbon nickel-chrome steel and the cap, there have been no radical improvements in armor-piercing projectile manufacture, other than a gradual in-

crease in skill of manufacture. Up until comparatively few years ago armor piercers were always made from crucible steel, but in the late nineties the use of small open hearths began and now most armor piercers are made from open-hearth and electric steel.

Manufacture of Armor-Piercing Projectiles.

646. Open-hearth steels—acid, basic, and electric—are used for these projectiles, but the melting is given far greater care than is received by the average commercial steel.

The ingots are cast nose down in iron moulds in order to chill them rapidly to prevent piping and injurious segregation.

There are two general systems of forging. In one the ingot is cast of greater diameter than the finished projectile, and is forged down, being lengthened in the process, under a press or hammer, and in this process the cavity is bored out. In the other process, the ingot is of smaller diameter than the finished projectile, is upset in a die under a press to the proper diameter, and its base is then pierced by a punch to form the cavity, the rear walls of the body being somewhat extruded. In the first process mentioned the grain or fiber of the steel is longitudinal whereas in the other process it is transverse.

The rough forgings are then annealed, after which they are rough machined nearly to size. The next step is a series of heatings and quenchings in oil and hot water for the purpose of refining and fibering the grain structure. After this treatment the forging is turned to exterior and interior dimensions, allowance being made for the fitting of base plug, and finishing of band score and bourrelet.

The next step is the hardening, which is accomplished by a graduated heating beginning with the point followed by a complete quench in agitated cold water. This puts the entire projectile in an exceedingly hard condition. The heating for this treatment is generally accomplished in a bath of molten lead, such procedure being conducive to accurate control of both temperature and position of application of heat. After this the base of the projectile is heated to a lower temperature than was used for quenching and upon withdrawal from the bath or furnace is suspended nose down and immersed up to the bourrelet in agitated cold water. This procedure draws or tempers the rear portion

while preserving the hardness in the head. The result is an exceedingly hard head to the rear of which the hardness gradually decreases with increase in toughness. The hard head is to effect the smashing of the plate's face while the tough rear is to support the head and stand the breaking strain of angle impact. (See Plate II.)

Finally, the projectile is sand blasted, the band score is finished and the band pressed into place, the cap and wind shield is put on, the bourrelet is ground, the band is turned to size and the base plug fitted.

647. The cap follows, in general, the same methods of manufacture and treatment as are applied to the projectile, although, of course, no special ingot is made for it. After forging it is annealed and rough turned, is then fibered, then finish machined, except threading for the wind shield, then decrementally hardened and finally finish turned and threaded and installed. Caps are made of the same kind of steel as are the projectile bodies, except that the carbon, nickel and chromium are not so high.

Caps are secured to the projectile by several methods. The one most commonly used consists in peening the skirt of the cap into notches cut in the ogive of the projectile. Fig. 114, showing an armor piercer in the banding press, also shows the notches in the ogive. Another method consists in soldering the cap to the ogive with a special low melting point solder. Such a solder is required to prevent the heat necessary for soldering from drawing the temper of the ogive.

Caps should be held securely in place, and it is quite probable that their efficiency on oblique impact is materially affected by the security of the bond. The notches in the ogive are certainly no source of strength. The use of solder is therefore looked upon with favor by many ordnance engineers.

It occasionally happens that caps become loosened by rough handling. Such projectiles should be returned to an ammunition depot for recapping.

648. The wind shield is made of either cast iron or forged mild steel and has no special strength other than that necessary to prevent destruction during handling and set-back. Wind shields are generally screwed on the cap, and frequently the thread is cut on a tapered surface. After screwing home they are "set" by a

center punch at the joint. They sometimes become loose in handling and in that event they should be tightened and reset.

649. Base plugs are simply ordinary good quality nickel-steel. The only special requirement is that their longitudinal axis should be normal to the longitudinal axis of the original ingot, a precaution taken to insure the maximum stregnth against shear or collapse under the chamber pressure of the gun, and to prevent piping or porosity from leading flame or gases in to the bursting charge. This latter precaution is taken with *all* projectile base plugs and will not be referred to again under other projectiles.

650. The steel for A. P. projectiles is the finest quality, nickel-chrome steel. Due to the comparatively small mass and more convenient size the carbon can be carried much higher than is possible in armor manufacture. For instance, we find the carbon content as high as .75 per cent. Similarly the chromium can be carried a little higher and we find the chromium content as high as 2.60 per cent. The nickel runs about the same as for armor.

Penetration.

651. Calculations as to penetration are all based on the DeMarre formula, which was discussed under Armor, although with less reliability than in the case of armor. A projectile may penetrate or "defeat" a plate but break up in the process, which will, of course, prevent it from being burst. In considering penetration from the projectile standpoint, the standard of performance must be effective bursting condition after penetration. Effective bursting condition is generally taken as complete integrity of the cavity. Thus the projectile may loose its nose, or even a large portion of the head down to about the bourrelet, but it is considered to be effective if the cavity is not exposed by cracks or fractures. (Plate II.)

When a projectile strikes a plate normally and penetrates, without deformation, just so far that its bourrelet has passed through the plate and beyond all ragged edges, it has delivered to the plate all its energy, except for the heat generated in the projectile, which is comparatively slight. Now, it is generally accepted that such a condition represents the maximum delivery of energy which a projectile can accomplish. At higher velocities it is probable that the plate requires less energy to accomplish its defeat. No demon-

stration of the accuracy of this theory can be made as no satisfactory device has been developed with which to measure residual velocities, but it is founded on considerable observation. Such a theory being correct, it follows that, for normal impact, the higher the striking velocity the *less* the strain on the projectile.

Now, as the angle of obliquity is increased from normal very different conditions are imposed. The primary phenomenon is that the projectile generally tends to readjust its axis *toward the normal,* or in other words, strives to seek normal penetration. This action, of course, introduces violent side strains, and when projectiles break on angle impact they clearly show this side strain by breaking across the body. The fact that rotation still persists must be remembered. Now it is clearly evident that in oblique impacts, the greater the velocity the greater must be the side or twisting strain.

To reduce the combination of the two conditions mentioned above to mathematical terms has so far proved impossible. In comparing projectiles, therefore, their relative efficiency can only be determined by confining the comparison to certain arbitrarily fixed conditions. For instance, we may fix a specific angle of obliquity and vary the velocity to effect comparison or we may fix the velocity and vary the angle of obliquity to effect comparison. Or, on the other hand we can fix the velocity and obliquity and vary the plate thickness required to defeat the projectile.

The Action of the Cap.

652. Various theories have been advanced as to the reason for the increase in penetration secured by the application of the cap. The simplest, and perhaps the most reasonable, is that the cap acts to break down the initial strength of the plate, allowing the nose to reach an already strained surface and then provides powerful circumferential support to the point and nose as they begin to penetrate the hard face, maintaining the support until they are well into the plate. This theory is supported by the fact that an un-capped projectile will penetrate a non-face-hardened plate with the same velocity as will a capped projectile, in fact with somewhat less velocity, as experiment has shown; the slight decrease being ascribed to the adding of the thickness of the cap to that of the plate. In comparing capped and un-capped projectiles against

face-hardened plate, recent experiments with 8-inch projectiles have shown that equal penetration can be secured when the energies are as about 5 to 9.

And finally the cap has the effect of increasing the *biting angle;* that is to say, a capped projectile will "bite" or fail to glance off at greater angles of obliquity than will the same projectile without a cap. This is due to the greater bluntness of the front end of the cap.

Form of Internal Ogive.

653. The shape of the ogive of the projectile itself has considerable effect on the efficiency of the projectile. The curvature of the ogive was increased to about 2.5 calibers because of the desire to reduce air resistance and this curvature was retained under the cap after its adoption. Shorter curvature is desirable, however, to secure a shorter projectile, and the modern tendency is to fix the ogive radius between 1.5 and 2.0 calibers.

Common and Class B Projectiles.

654. The development of the common and Class B projectile followed logical channels, being based on the attack of unarmored vessels, the upper works of armored vessels, earthworks and fortifications.

As a general rule the design and selection of materials of these projectiles is predicated, in so far as is consistent with efficient operation, on *cheapness* and *quantity production.* In fact, the co-ordination between design and quantity production is of almost vital importance. These considerations led to the selection of plain .45 per cent to .60 per cent carbon basic open-hearth steel, and the adoption of a design which reduces the number of forging and machining operations to a minimum. In designs requiring the maximum attainable weight of bursting charge, or calling for peculiar interior arrangements, greater strength per unit of area will probably be required, in which case a higher carbon or even a nickel-steel may be necessary.

Methods of fabrication differ with the caliber and type. In large calibers each projectile is made from a separate ingot, while in medium calibers large ingots are "cogged down" in a rolling mill to billets of round, square, or polygonal section and then cut

or broken to proper length. The ends of these blanks are usually inspected to eliminate those which contain piping or injurious segregation.

655. Considering major and medium caliber projectiles, and the ingots or billets made for them, as mentioned above, fabrication continues, in general, as follows (Fig. 117):

The projectile blank is heated, placed in a die approximating the exterior contour, nose down, but of excess diameter, and then pressed under the plunger of a hydraulic press, thus forming the ogive. A piercing die or plunger of slightly less diameter than the cavity is then forced into it, which forms the cavity. These two steps can be done with one heating.

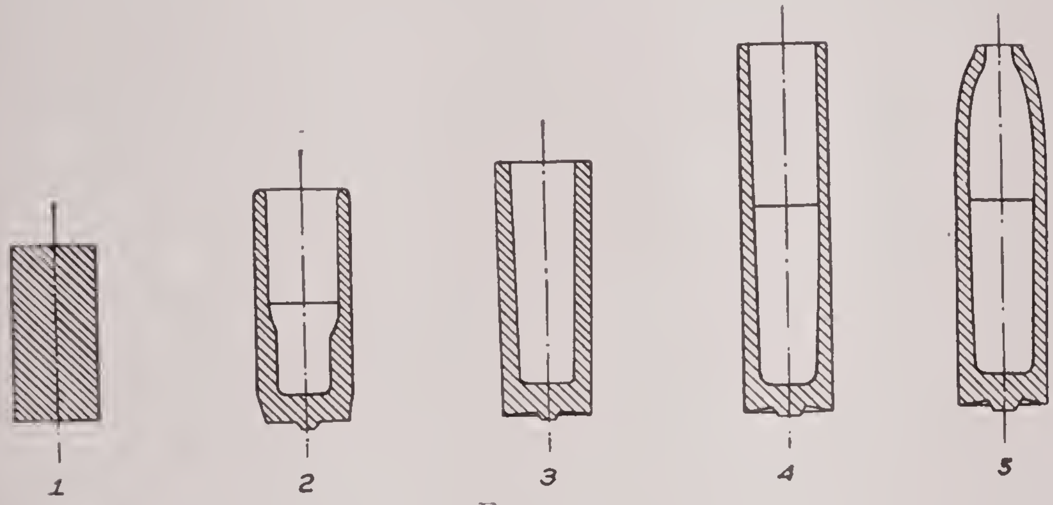


FIG. 117.

In some projectiles this is the only forging required, but generally the extrusion performed by the piercing die is insufficient to make the cavity long enough. In this case, which is quite general, the forging or blank is reheated, and placed in a draw-bench, the nose being placed in a die containing a circular hole slightly larger than the finished diameter, and it is then forced through this drawing die by a hydraulically operated plunger which is inserted in the already partially formed cavity. This drawing process forces the sides back over the plunger, thus extending the blank to the required length. In some cases more than one draw is required, and this is generally performed in one heat by forcing the forging through several rings or dies in succession in the same draw-bench. The method just described applies, of course, to open-

base projectiles. Where the base is to be solid and the nose is to be open the same general process is followed, except that the projectile is worked from the base instead of from the nose.

The blank is then generally annealed, or normalized, and if high physical properties are required, it may be heat-treated to secure them. It is then passed to the machine shop for finishing.

The finishing consists in turning and boring to the correct dimensions and tolerances, banding, fitting the plug, painting the interior of the cavity and inspecting and stamping for shipment. As a general rule all surfaces are finish machined except as noted below. Many efforts have been made to omit the machining of the cavity but the forge finish is not satisfactory because the forging temperature is so high that a rough and scaly surface results.

Some projectiles are fitted with heavy nose or base plugs, others have smaller adapters to carry the fuse, and others may be designed to receive the fuse itself. In most of these classes the cavity is always of larger diameter than is the hole for these fittings. This condition is met in two ways.

Where the hole is large and the amount of metal to be removed from the rough forged cavity is small, or where the projectile is completely heat-treated, the interior is finished in a boring machine or lathe, using a tool on the end of a bar which is inserted in the hole. This bar is swung on a pivot in order that the tool can be made to follow the desired contour of the interior.

Where the cavity is large and entails the removal of considerable metal, or where the forward or after fuse or plug hole is so small as to render machining impracticable, an entirely different process called *noseing-in* or *baseing-in*, as the case requires, is employed. Here the inner portion of the cavity is machined to size while the outer portion of the cavity is machined to a cylindrical or nearly cylindrical size, any shoulders or seats being also partially machined. The exterior surface of the projectile, in the wake of that portion of the cavity which is to be closed in, is then turned to the reverse curvature of the cavity, or in other words, the approximate contours of the cavity and outside are exchanged and reversed. That part of the projectile which is to be closed in is then carefully heated in a non-oxidizing flame, and is then either forced into a die, under hydraulic pressure, which is cut to the

proper exterior shape, or is pressed into shape under radial pressure. As was stated above, this process can be applied to either the ogive or the base. Fig. 117 shows the various stages of piercing, drawing and noseing of a 6-inch army shell.

This operation can be so satisfactorily performed that no machine work is necessary on the closed-in portion except the fitting of screw threads and gas-tight seats.

It is generally customary to select tensile-test specimens from heats or lots after all forging or heating is completed, in order to insure that uniform and satisfactory results are being secured.

The processes referred to above apply to practically all kinds of projectiles, except armor piercers and minor-caliber projectiles.

Minor-caliber projectiles are generally machined from round rolled bars, the forging to shape with final finishing being more expensive than complete machining.

Base plugs, fuse-hole plugs, adapters, and the miscellaneous interior parts of shrapnel, illuminating projectiles, gas and smoke projectiles, etc., are manufactured by the various drop-forging, drawing, and machining processes covered in text-books on mechanical processes.

Special Projectiles.

656. Shrapnel (Fig. 118).—This type of projectile is designed for use against personnel and its only naval use is, therefore, in

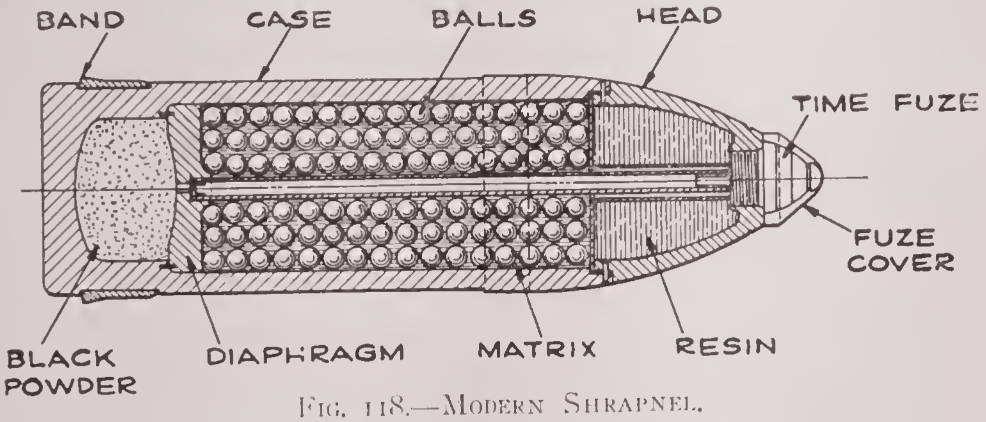


FIG. 118.—MODERN SHRAPNEL.

connection with landing parties, bombardment of fortifications and attack of aircraft. It is interesting to know that the name is derived from the inventor who brought it out in Europe in 1784.

The most common form of shrapnel consists of a case in the rear of which is a black-powder bursting charge, connected to a

nose fuse by a central explosion tube around which is packed a large number of lead (88 per cent)-antimony (12 per cent) balls held securely in place by a matrix of hot-poured rosin. When the fuse acts the balls are expelled forward by the bursting charge and scatter in a cone-shaped cloud. Shrapnel are, however, frequently given other features. For instance, a high explosive may replace the rosin to increase the violence of the burst and the area of damage; or there may be a heavy head with a high-explosive burster and suitable fuse in order to follow the cloud of balls with a secondary explosion. And finally the balls may be replaced by small hollow open-ended cylinders in which phosphorus or other incendiary compound is packed, the object of this design being to add to the local explosion and distribution of missiles the probability of creating a conflagration. This design is particularly valuable against aircraft of all descriptions, especially those which employ hydrogen.

657. Illuminating projectiles.—In this type we have a case, similar to a shrapnel case, with a very small burster in the front end just abaft the fuse, and an interior assembly of a star or candle with parachutes, and a very lightly held base plug. The explosion of the burster, or as it should be called the expelling charge, forces out the base and the interior assembly. It is quite desirable to expel the assembly with considerable velocity, at least 300 to 400 f. s. relative to the case, in order that it will have as small a velocity, in space, as is possible. It would be preferable to have the assembly expelled at the same velocity as the case is traveling, but at present this is not possible. The star or candle is a steel container in which is packed, under heavy pressure, an illuminating compound in which magnesium is an important constituent. The explosion of the expeller ignites the candle or star. The closed end of the star container is attached to a wire rope which carries a series of silk parachutes, the number depending on the weight of the star. These parachutes are carefully folded and they, and the wire, are so rolled that, upon expulsion, they open or come into action in succession beginning with the one nearest the star. The parachute nearest the star is quite small, only 4½ inches in diameter for a 3-inch projectile, and they increase in size until for a 5-inch projectile, for instance, the last parachute is about 3½ feet in diameter. The small parachutes are called

retarding parachutes and the last and largest the sustaining parachute. From this description the action of the assembly upon ejection is easily seen. The fast moving, heavy and burning star is gradually slowed down by the retarding parachutes, the opening of successive parachutes increasing the effective area and thereby maintaining a more or less constant retarding force, until by the

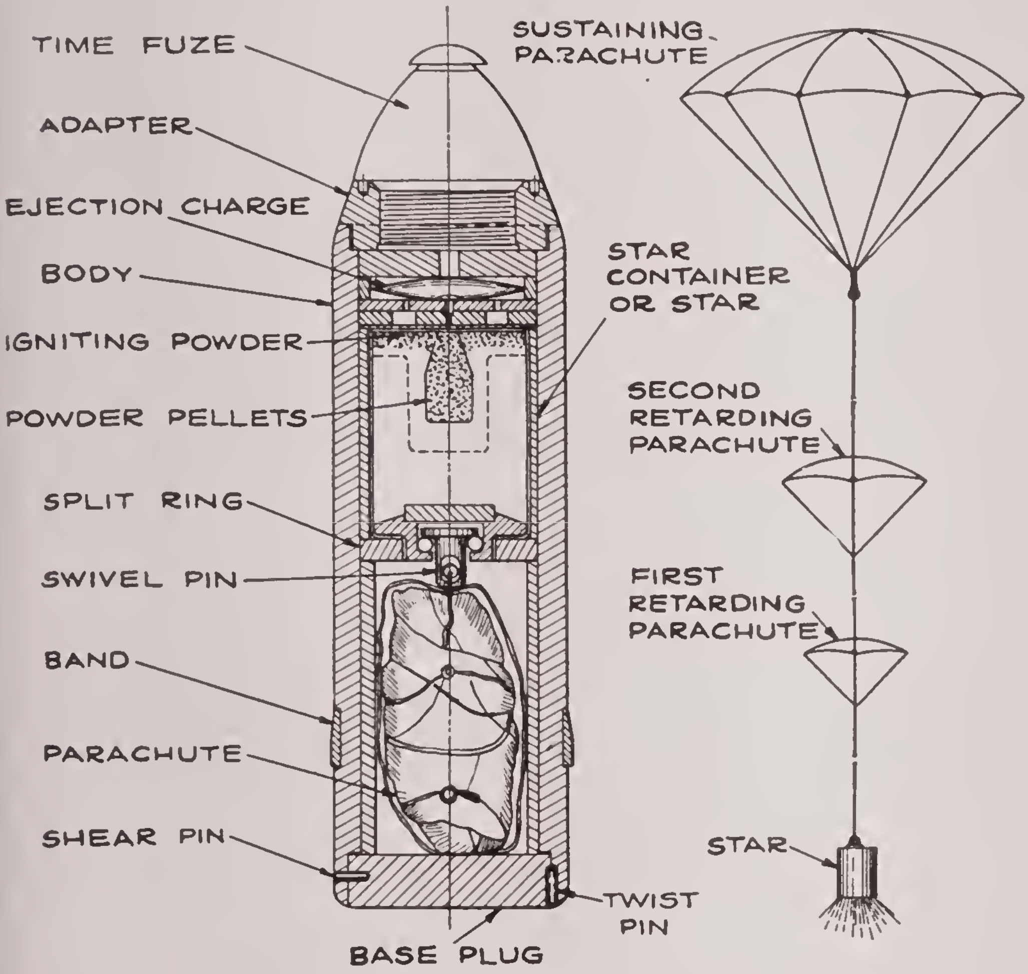


FIG. 119.—ILLUMINATING PROJECTILE SHOWING PROJECTILE AS ASSEMBLED AND DESCENDING STAR.

time the sustaining parachute unfolds it can open without danger of being torn to ribbons. This action is similar to that of a recoil brake. The wire for a 3-inch projectile is about 15 feet long and carries three parachutes, while in a 5-inch projectile the line is about 40 feet long and carries seven parachutes. The entire assembly gradually tails vertically and sinks earthward with comparatively slow speed, the light of the star being thrown down-

ward. As there is no need, with illuminating projectiles, for either great accuracy or a flat trajectory, fineness of exterior form is sacrificed to secure the maximum size and weight of star.

658. **Smoke and gas projectiles.**—These, when specially designed for the purpose, are quite similar to any high-explosive or Class B projectile so far as the projectile itself is concerned, the difference lying in the kind of fuse, contents, and method of loading.

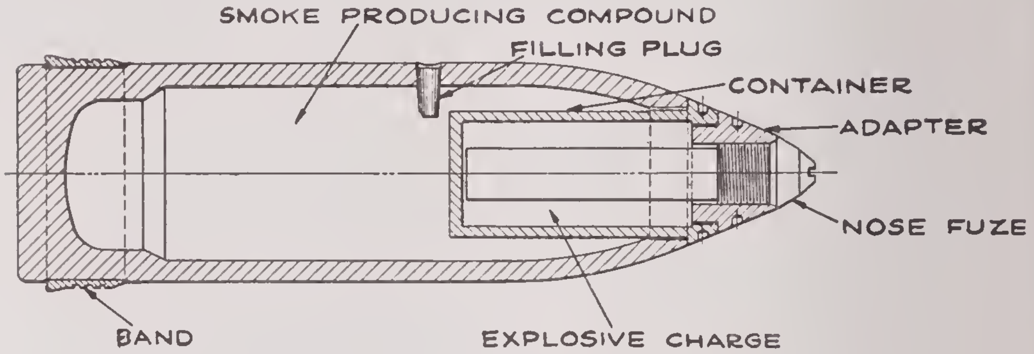


FIG. 120.—5-INCH (50) SMOKE PROJECTILE.

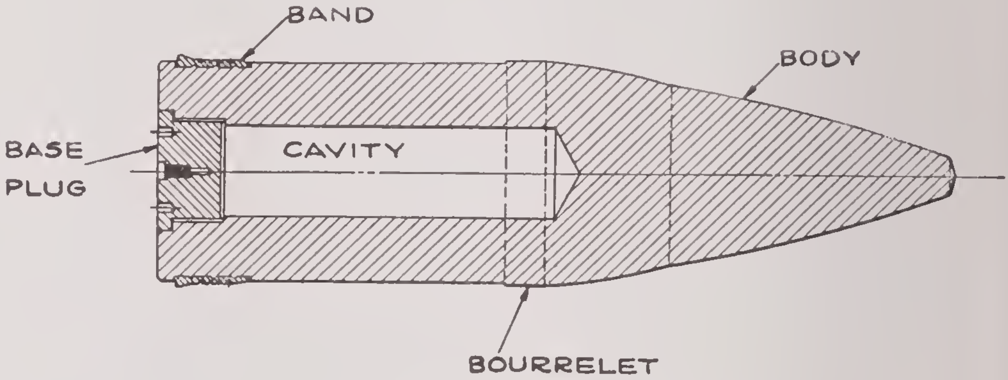


FIG. 121.—12-INCH PROJECTILE (TARGET).

659. **Target projectiles.**—Economy requires that target projectiles be made of the least expensive materials. They are therefore made of cast iron. A good grade of cast iron, and efficient methods of casting are necessary, however, to insure that the setback and centrifugal force do not cause fracture, either in the gun or in initial flight. They are so designed that they are similar to their prototypes in exterior shape, weight and balance. No economy can be secured in the rotating band, as it must function in the normal way.

660. Proof shot, sometimes called "slugs," are solid cast-iron shot with a square forward end. From the forward edge of the rotating band to the rear, they are identical in shape with the standard projectile of their caliber, but their only other similarity is their weight and bourrelet diameter. As a result of this design their behavior *in the gun* or interior ballistics is similar to, while their flight is much shorter than, that of the standard projectile. They are used for proving-ground work and spotting practices.

661. Marker projectiles.—A projectile similar to an illuminating projectile is fitted with a buoy in place of the star and parachute assembly and a water-impact fuse. The buoy carries a burning charge, principally compounds of phosphorus, which are ignited by the fuse, but which can not be put out by water. The burst expels this buoy, thus leaving a comparatively permanent mark of the position of the fall. This projectile is to indicate the position of hostile submarines to pursuing or hunting vessels.

662. Line-carrying projectiles.—These are simply loose-fitting slugs which carry a rod extending to the muzzle with an eye in the end, to which is attached a light cord. The projectile turns around immediately after firing, and is held to its trajectory by the strain of the trailing cord. The cord is coiled down on deck and, after the projectile has passed over the target, a heavier line is bent to it and with succeeding heavier lines a hawser can finally be run. A range of about 350 yards can be secured in a 3-pounder saluting gun.

CHAPTER XVI.

AMMUNITION AND AMMUNITION STOWAGE.

PART I.

Definitions.

663. **Ammunition** is the general term applied to the assembled charges, cartridges, projectiles, etc., of all forms, used for loading guns. It is of three kinds named from the purpose for which it is prepared, *i. e.*, "*service*," "*target*," or "*drill*." All ammunition is of one of two types depending on the type of gun for which intended, "*case*" or "*bag*" ammunition.

664. **Case ammunition** is made up with the powder and primer contained in a brass cartridge case which fits the chamber of the gun snugly. The "*primer*" contains the "*ignition charge*." The case is sealed by the projectile fitting into the mouth, or by a cork composition mouth plug, thus making it air-tight for the protection of the powder. The former is called "*fixed case*" ammunition and the latter "*separate case*" ammunition. All guns of 4-inch and below take "fixed case" ammunition, certain 4.7, 5 and 6-inch guns take "separate case" ammunition and all other guns take "bag" ammunition.

665. The advantages of using case ammunition are:

(a) Rapidity of fire.

(b) Ease of handling, assembling and loading.

(c) Charge safe from sparks in loading.

(d) Less danger from flare-backs.

(e) Less chance of double loading.

(f) Cheaper to prepare.

The disadvantages are:

(a) Reduced chances for firing in case of misfire, as primer cannot be replaced.

(b) Increased weight.

(c) Danger from split cases.

(d) Difficulty in loading in case of a loose projectile.

666. **Bag ammunition** is that made up with the powder contained in one or more silk cloth bags with an ignition charge in

the base of each bag. The primer is held in a firing lock screwed on the end of the mushroom stem. This type is made up in two ways, loose and stacked. In the former the powder is dumped loosely into the bag and the bag is then rolled and laced tightly to make a compact unit. In the latter, the powder grains are stacked in seried rows, each grain in a layer on end, and each layer placed successively in the bag and the bag sewed up and laced tightly. Stacked charges give a more compact, stiffer unit, easy to handle, occupying less space and eliminating a serious drawback in loosely packed bags, namely the cutting of the cloth by the sharp edges of the grains. Powder for service weights of charge for 12-inch guns and above, except the old 13-inch guns, is always stacked.

667. **Ammunition details** is the term applied to the component parts, exclusive of explosives, used in preparing ammunition and comprises the following:

- Primers.
- Cartridge cases.
- Ammunition boxes or tanks.
- Powder tanks.
- Fuses.
- Tracers.
- Projectiles.
- Powder bag cloth.
- Distance pieces.
- Wads.
- Fuse covers.
- Mouth plugs.

Ammunition Details.

668. **A primer** is a specially constructed device, the flame from which, when it is exploded by the direct action of the firing mechanism, ignites the powder charge in the chamber of the gun, and causes the explosion; either directly, as in case ammunition, or indirectly through the agency of the ignition charge, as in bag ammunition. This action is called the ignition. Smokeless powder is difficult to ignite with the application of a small flame. This is well shown by the ignition of a powder grain in air with a match, whereby it will be seen that the grain ignites slowly, burns relatively slowly and is easily extinguished. To provide a rapid and certain inflammation of the charge, an amount of black powder is used commensurate with the weight of charge and size of the smokeless-powder grain. Black powder has been found to be the substance best adapted for this purpose due to the rapidity and ease with which it is ignited, and the intense flame it gives off. As the function of the primer is to initiate the explosion, the design

depends on the amount of ignition powder required and the form in which it is provided.

669. **Types.**—There are two general types of primers, one containing in itself the necessary amount of ignition powder, called the "case primer," and the other containing only sufficient black powder to direct a flame on to the ignition charge contained in the powder bag, called the "lock primer." Where it is necessary to increase the amount of ignition in a "case primer," the stock is lengthened to hold the additional black powder. The primer is then termed an "ignition case" primer to differentiate it from the short case primer. Primers may be divided in another way according to the method in which the ignition is initiated, as simple "percussion primers" where the flame is caused by the action of a hammer on a fulminate cap; simple "electric primers" where the flame is caused by the heating of a high-resistance wire igniting a wisp of guncotton; or a "combination primer" combining both the above features. Formerly many types were issued to the service but they have been narrowed down now to three types for case guns and one for bag guns. They are (1) the percussion case primer, (2) the percussion case ignition primer, (3) the combination case ignition primer, (4) the combination lock primer.

Percussion fire only is provided for ammunition for 3-inch guns and below and combination fire is provided for all above 3-inch. This division is made on account of the requirements for assembly and loading the ammunition and the handling of the gun. The percussion element is required for the larger guns in case of failure to fire electrically.

670. **A percussion primer** is loaded with a primer cap and a small charge of black powder depending on the size of the gun for which intended. An electric primer has in place of the cap a platinum bridge with a small wisp of dry guncotton wrapped on it, in an ignition chamber, which is filled with a mixture of pulverized guncotton and fine black powder, and, in addition, a charge of black powder. The combination primer has both the cap and the platinum bridge so arranged that the flame from either will ignite the black powder. The primer cap composition usually contains fulminate of mercury. This substance easily explodes by percussion, friction, heating to 300° F., electric spark, or by contact with concentrated sulphuric or nitric acid. While weight for

weight its explosive force is not much greater than that of gunpowder, it is very sensitive, especially when mixed with ground glass or sand. It is very sudden and positive in its action, as more powerful explosives of equal weight when substituted for it often fail to produce an explosion of the first order. It is never used alone as a cap filler but its explosive properties are moderated by the admixture of mealed powder, potassium nitrate or chlorate, or similar substance, while its sensitiveness may be increased by the addition of a small quantity of ground glass or similar substance. The cap used in navy primers is known as a "Winchester No. 2½" and contains 35 parts of fulminate of mercury, 35 parts of chlorate of potassium and 30 parts of sulphide of antimony.

671. An important phase of the service of a primer is the time interval in which it performs its function. The shorter the interval between the explosion of the primer cap and the ejection of the projectile from the gun the more efficient is the gun, for naval purposes in particular. Of this time interval a part is used up in the creation of a flame sufficient to start the inflammation of the powder, hence a primer must be suitably designed to obtain the best results. This accounts for the three different types used in case ammunition. If too much black powder is used, erratic pressures and velocities result, as is shown by the performance of the primer designed for a 4-inch gun when used in a 3-inch gun. In bag guns the primer interval is so nearly constant that the same type is suitable for all calibers.

672. Plate I, Fig. 1, shows a case percussion primer as used in the 1-3-6 pdr. and 3-inch low-velocity guns. It is simple percussion and contains only 45 grains of fine black powder, as this charge is sufficient to ignite efficiently the small powder charge required for these guns. It is assembled by forcing it into the primer aperture in the case, in a hand press.

Fig. 2 shows a case percussion ignition primer as used in the 3/50 gun. It has 110 grains of fine black powder. It is screwed into the primer seat in the cartridge case.

Fig. 3 shows the case combination ignition primer as used in 4-inch ammunition and above for case guns. It has 265 grains of fine black powder, and both the percussion and electric elements. It is also a screw primer.

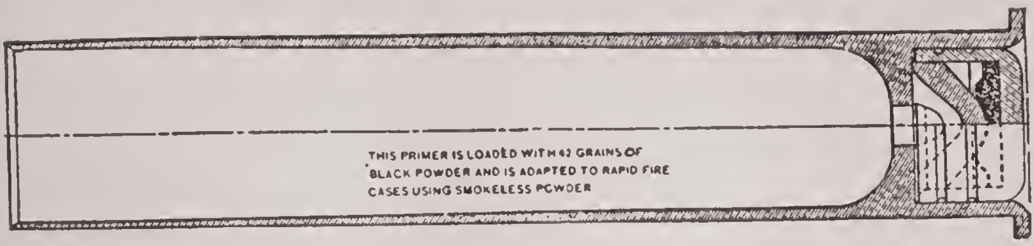


FIG. 1.—PERCUSSION PRIMER. (FOR 1-, 3-, AND 6-POUNDERS AND 3-INCH FIELD-GUN CARTRIDGES.)

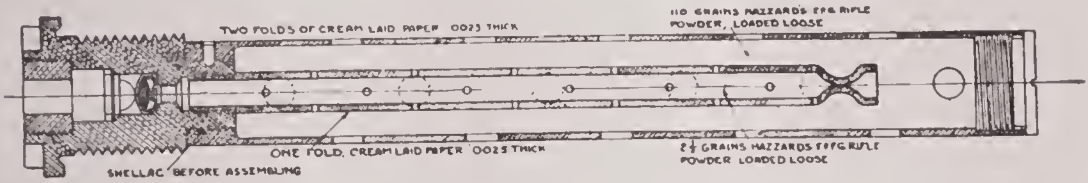


FIG. 2.—CASE PERCUSSION IGNITION PRIMER.

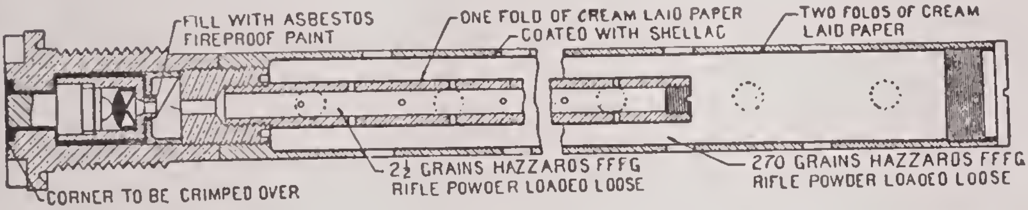


FIG. 3.—CASE COMBINATION IGNITION PRIMER.

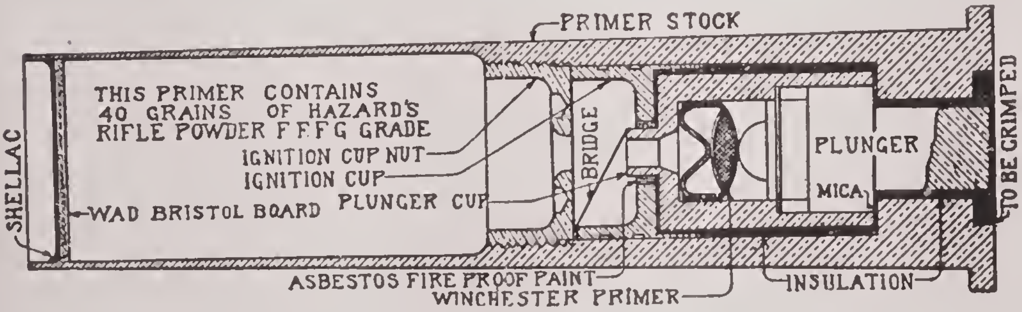


FIG. 4.—COMBINATION LOCK PRIMER.

PRIMERS.

673. The essential features of the case ignition primers are the extension magazines holding the ignition charge, the ignition tube and the screw thread. The extension carries the ignition into the center of the powder charge and when exploded directs the flame outward through the holes in the extension into the body of the powder charge. The interior brass tube, called the ignition tube, contains a small charge of from $2\frac{1}{2}$ to $3\frac{1}{2}$ grains of black powder and acts as a train between the cap and the ignition charge. The holes in both tubes are sealed by manila paper tubes and shellac.

Fig. 4 shows the combination lock primer containing only 30 grains of black powder. The method of insulation to form a circuit is shown clearly by the heavy black lines.

Simple electric primers or simply percussion lock primers may be met with in service but they are remnants left from previous stocks and are for drill and test purposes only. A special short case percussion primer is used for " non-recoil " gun ammunition.

Cartridge Cases.

674. The powder charge for some guns is put up in brass cartridge cases, which are hollow cylinders with flat heads, shaped to fit the chamber, those for late guns being bottle necked. The head has a rim for the extractor and a central aperture for the primer. The cases are drawn from solid disks in successive passes in hydraulic presses equipped with suitable dies. The disks, 70 per cent copper and 30 zinc, when cast are very malleable and ductile and roll easily. The metal is bright yellow in color. Each case is carefully gauged, after machining, to ascertain that all dimensions may be within the tolerances allowed. It is of the greatest importance that each case should be interchangeable, that the extractor fits the rim, the primer fits the seat, the projectile fits the mouth, and that the length be correct so that the assembled charge will fit the gun.

Cartridge cases are reloadable, when they have been cleaned and reformed after firing. To reduce the preparatory work previous to reloading, the navy regulations state explicitly how they shall be handled after use. They are required to stand six service rounds without deterioration before acceptance from the manufacturer. This fact is established by firing a number from each lot at the proving ground. It frequently happens that cases will stand from 30 to 40 rounds before becoming useless.

The head of the case has an internal boss in the center which is drilled out and, when designed to take an ignition primer, the hole is tapped. It is of the greatest importance to have this aperture exactly concentric in order that the primer will be aligned with the firing pin. The depth of seating must be exact in order that the primer will be inset the required amount. If the primer is inset too much a misfire will occur, and if it is not inset a sufficient amount it is a source of danger in the event it is struck against a sharp object.

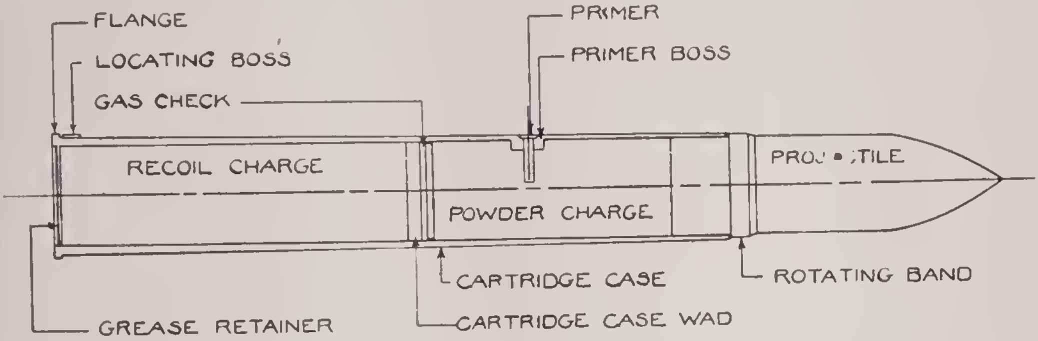


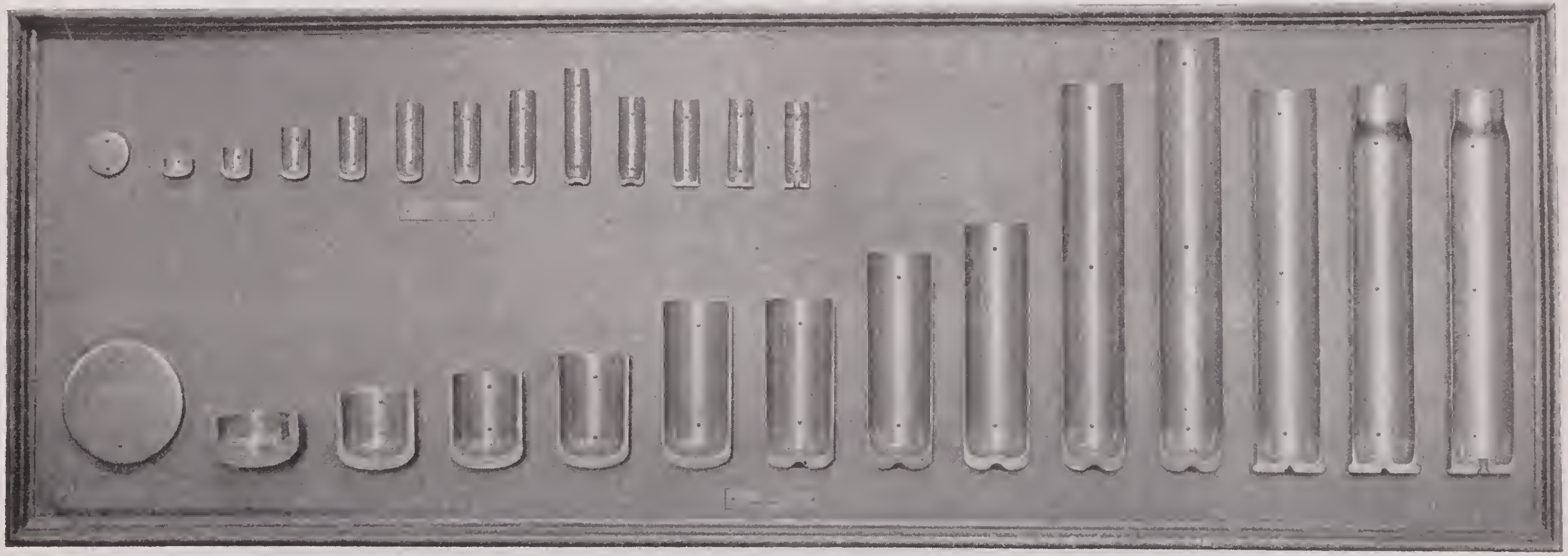
FIG. 122.

675. Non-recoil guns require special cartridge cases. These guns are used where it is desired to keep the recoil at a minimum. Where brass cases are used, the recoil charge is assembled in the rear as a part of the case. In one type, where it is desired to eliminate unloading, a steel case is used with a rotating band on the end of it. When the gun fires, the case is propelled to the rear and acts as a projectile, the rotating band preventing gas escape. The propellent charge is carried in this case and the assembly is the same as for regular ammunition. A special feature is the number of rings similar to the bourrelet of a projectile with holes through the case covered by shellacked paper. These holes permit the gas to escape so that the pressure is on the walls of the gun, thus preventing binding in the bore. As the firing lock is on the side of the gun the primers are assembled through the side of the cases. Special short primers are provided. A lug on the case engaging a slot in the gun admits of loading so that the primer will be in position opposite the firing pin.

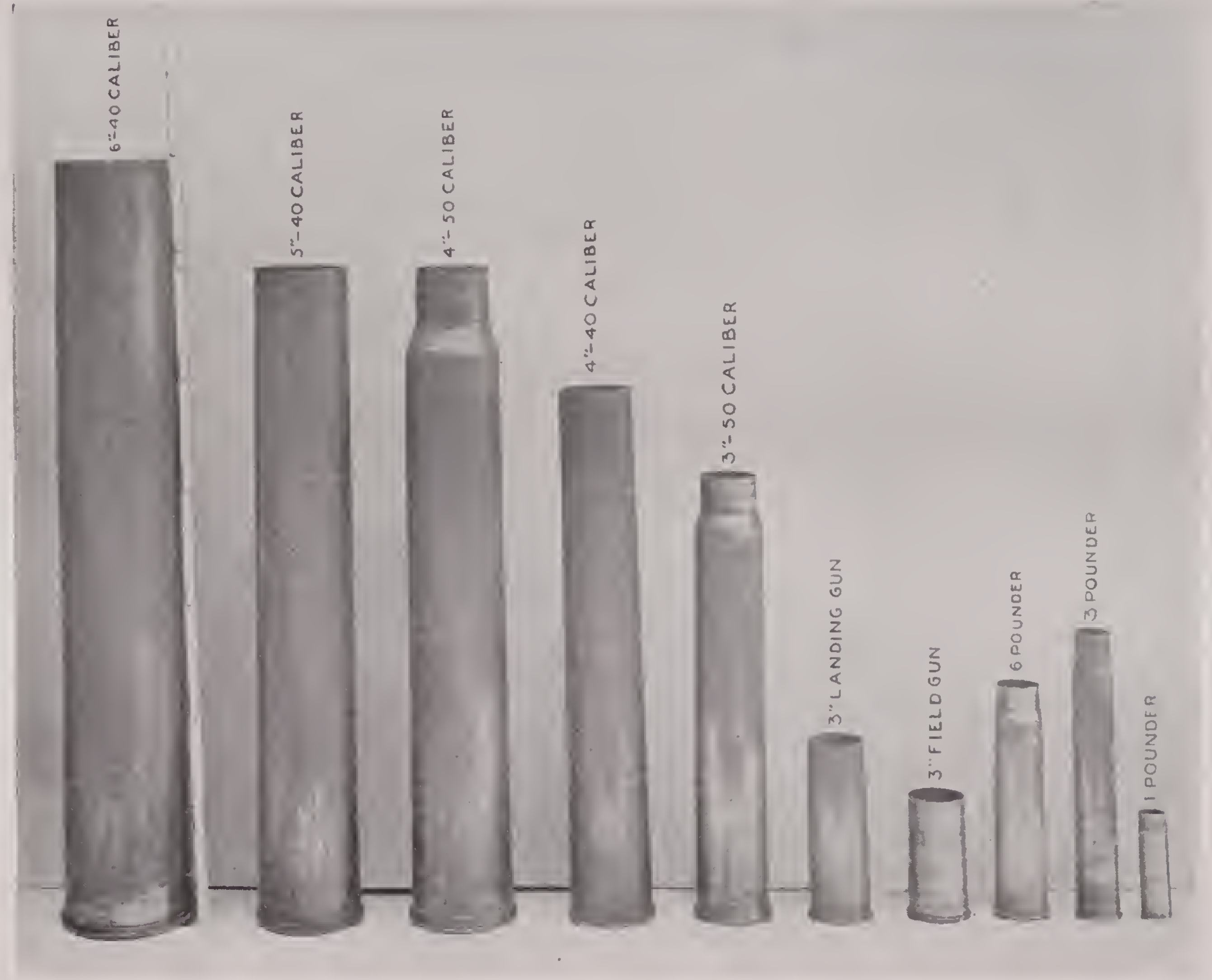
Plate II shows the steps in the manufacture of a cartridge case.

Plate III shows cases of different sizes.

Fig. 122 shows non-recoil gun ammunition assembly.



STEPS IN DRAWING FINISHED CASE FROM THE "BLANK."



CARTRIDGE CASES.


F.S.COM.SHELL
A.P.SHELL
F.N.SHELL
F.S.COM.SHELL
SHRAPNEL
F.N.SHELL
SHRAPNEL

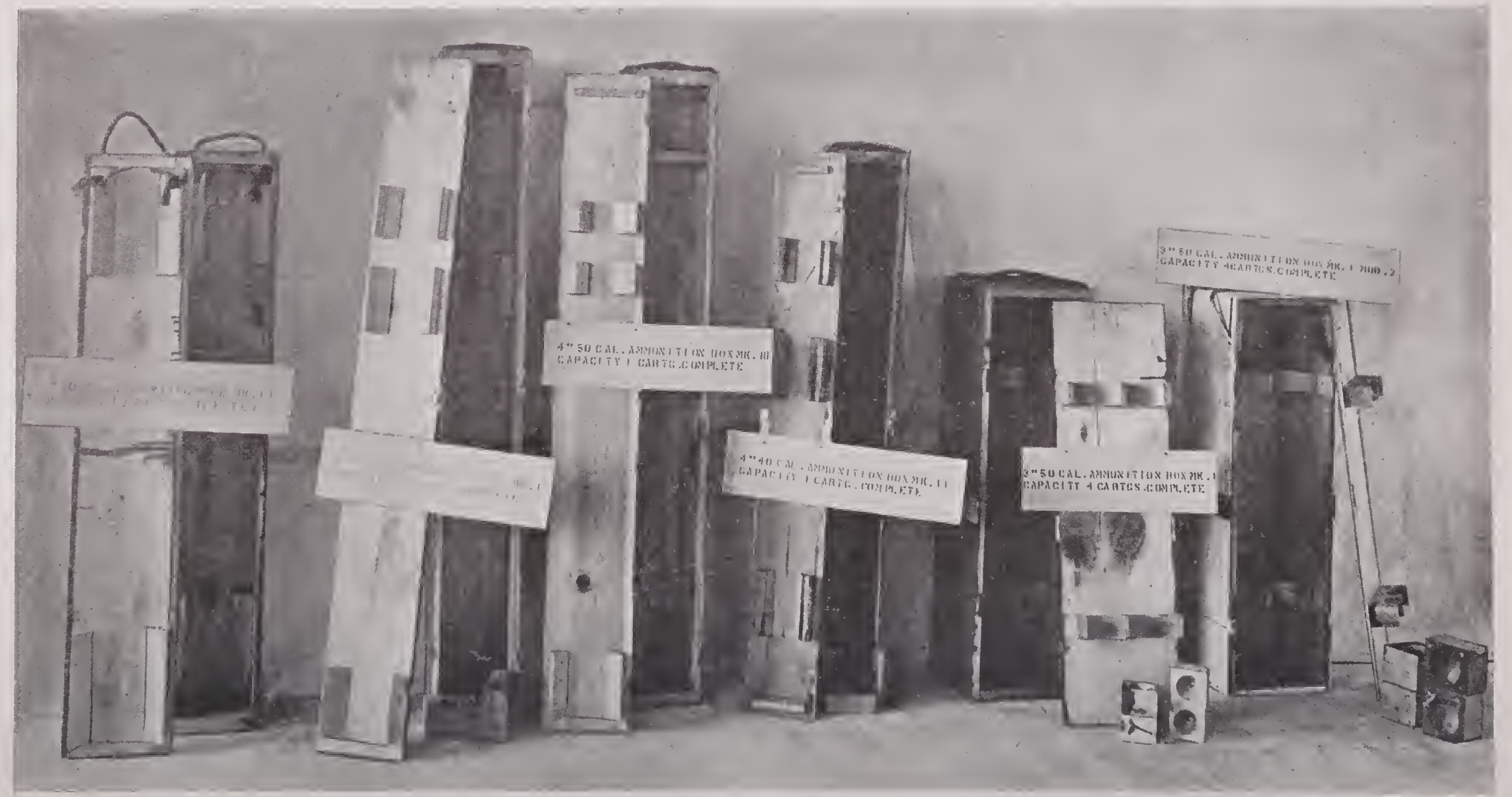
Ammunition Tanks and Boxes.

676. Case gun ammunition, after it is prepared, is packed in tanks or boxes for issue to the service. This is necessary for its safe transportation and stowage. Standard containers are used varying in size and capacity with the caliber of the ammunition. As many cartridges are packed in a container as will allow easy handling.

4-inch and above	one	per box or tank
3″/50	four	" " " "
3″/23	six	" " " "
6-pounder	eleven	" "
3-pounder	sixteen	" "
1-pounder anti-aircraft	one hundred per box	
1-pounder	sixty per box	

677. As the ammunition is stowed in a magazine remote from the guns, the containers must be strong enough to stand considerable handling, especially that which they undergo in passage up the ammunition hoists. The boxes are made of soft pine with one or more rope grommets for ease in handling. The tops are either loose and held in place with marline, or hinged and clamped.

678. Suitable racks or nests are provided in each box with wooden blocks to protect the ends of the cartridges and to hold them rigidly in place. Ammunition boxes, being of wood, are subject to easy destruction and are not water-tight. In consequence, the tendency in recent years has been to replace them with metal tanks. As the projectile or primer may leak the cartridge case cannot always be relied upon to remain air-tight, so that the present practice is to make the tanks airtight. This gives the additional advantage of good stowage in "ready service" racks on deck, where the ammunition is exposed to the weather. The tops are fitted with rubber gaskets and are secured by a lug and butterfly nut. The tanks are usually circular in cross-section, thereby changing the stowage arrangements from boxes, which are all rectangular in shape. The tanks are made from sheet metal with brass top and bottom rings. The body is galvanized after completion. The top and bottom rings are made strong enough to permit of stacking without the use of racks. Metal tanks are used for 4″/50 ammunition, and 3″/50 and 3″/23 for submarines.



TYPES OF CARTRIDGE BOXES.

TYPES OF CARTRIDGE BOXES.

Before acceptance, the tanks are required to stand an air-pressure test. Before issue to service, containers are painted and tagged to show their contents.

Plate IV shows different types of boxes.

Plate V shows different types of ammunition tanks.

Powder Tanks.

(Plate VI.)

679. Powder charges for bag guns are stowed in sheet steel or copper tanks. The considerations in the design of a powder tank are:

(a) Airtightness.
(b) Strength.
(c) Lightness.
(d) Quick opening.
(e) Stowage facilities.
(f) Handling facilities.
(g) Capacity.
(h) Nonacid surface inside.

680. As smokeless powder changes its ballistic properties when exposed to air, it is essential that the containers remain airtight, while in use for storage of powder. To effect this, the tank closure is fitted with a rubber gasket on which the cover is forced by various systems of dogs and nuts or cams, either fitted on the outside of the tank or contained in the cover itself. Self-contained closures with the necessary dogs not projecting beyond the limits of the body of the tank are considered more desirable, as there is less likelihood of loosening the cover, thereby causing a leak. The standard test for airtightness is to hold 5-pounds pressure for three minutes.

Plate VI, Figs. 3 and 5, shows dogs fitted on the outside; Figs. 2 and 4 show a self-contained closure.

681. Powder tanks must be strong enough to stand the necessary handling in stowage below and, in case of broadside guns, in handling in the ammunition hoists. They are designed with sufficient strength to withstand normal stresses but should never be subjected to knocks which may result in leaks. The main strength is placed in the top and bottom rings in order to permit stacking. Copper tanks are strengthened by wooden battens on the sides. Handles riveted to the sides are a source of weakness due to the pulling loose of the rivets when handling the tanks loaded.

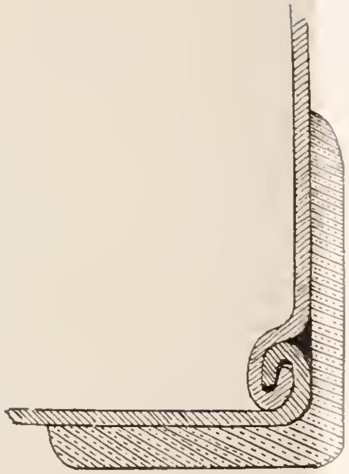


Fig. 1.—Bottom of Tank.

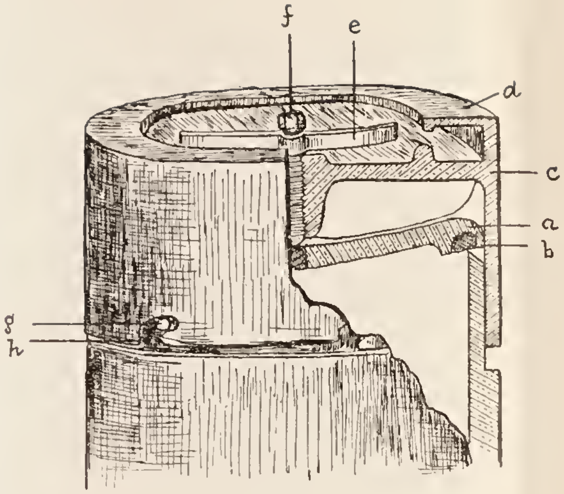


Fig. 2.—6-Inch Tank, Mark VII.

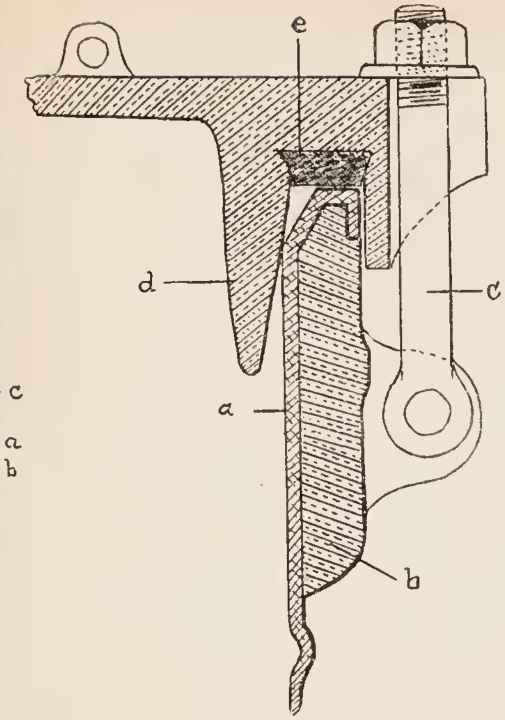


Fig. 3.—12-Inch Tank.

POWDER TANKS.

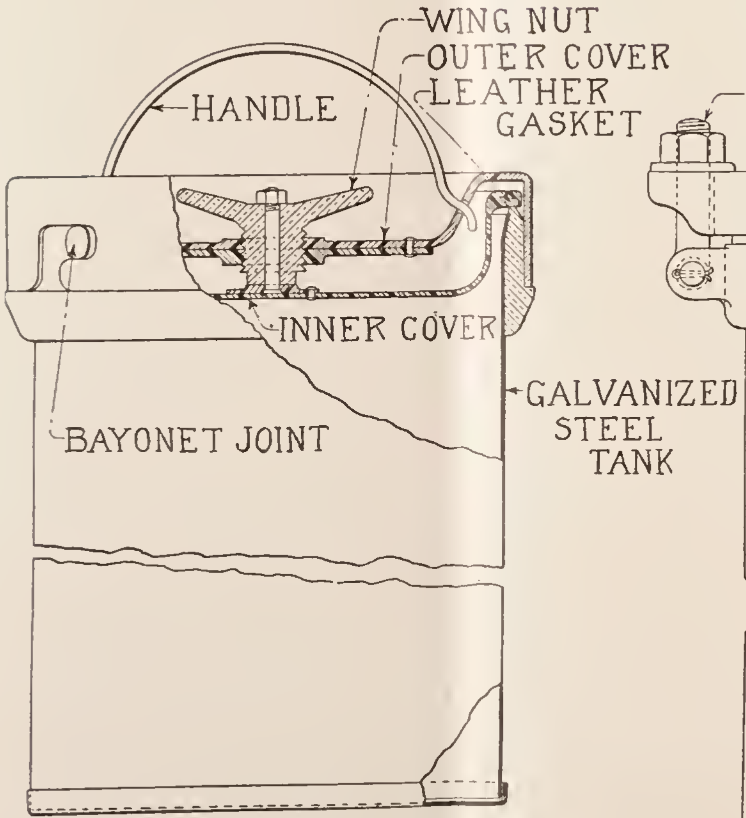


Fig. 4.

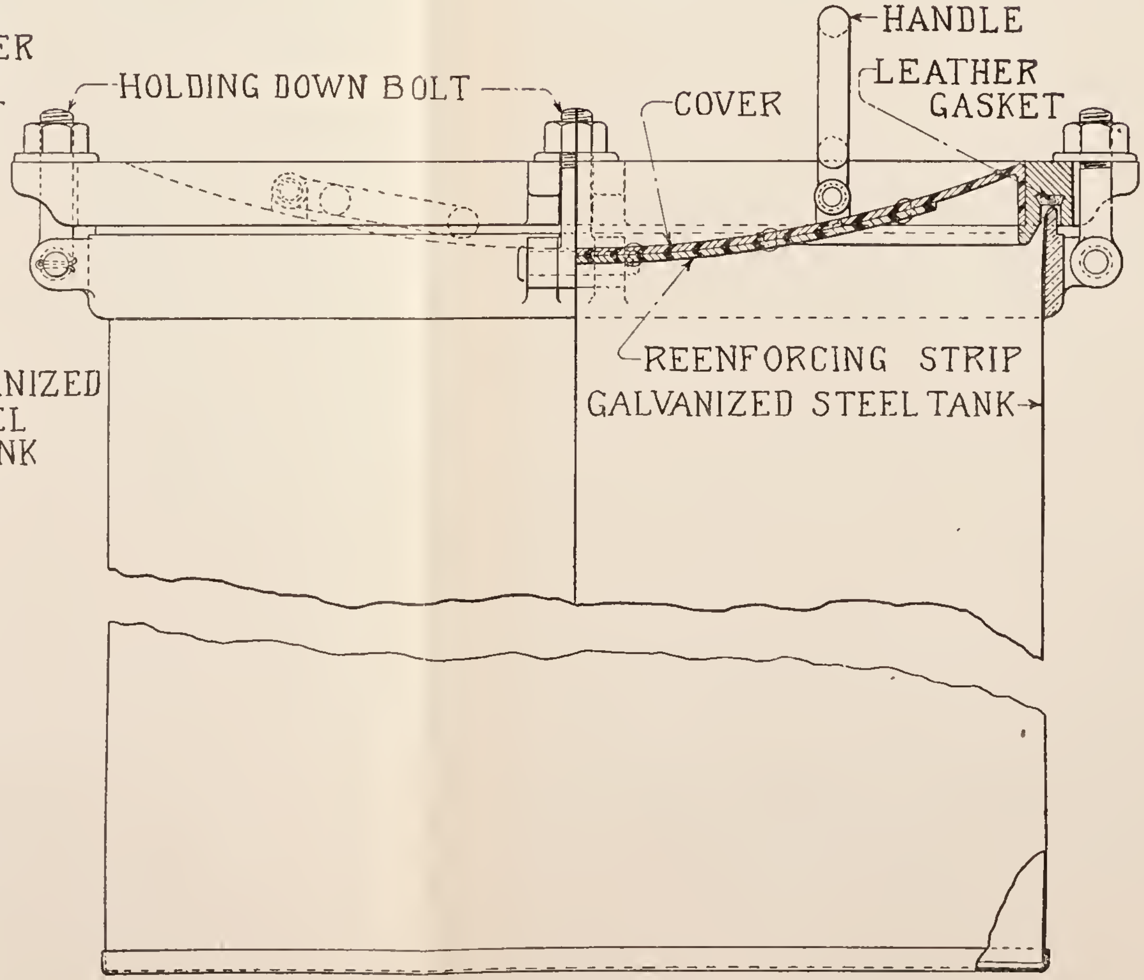
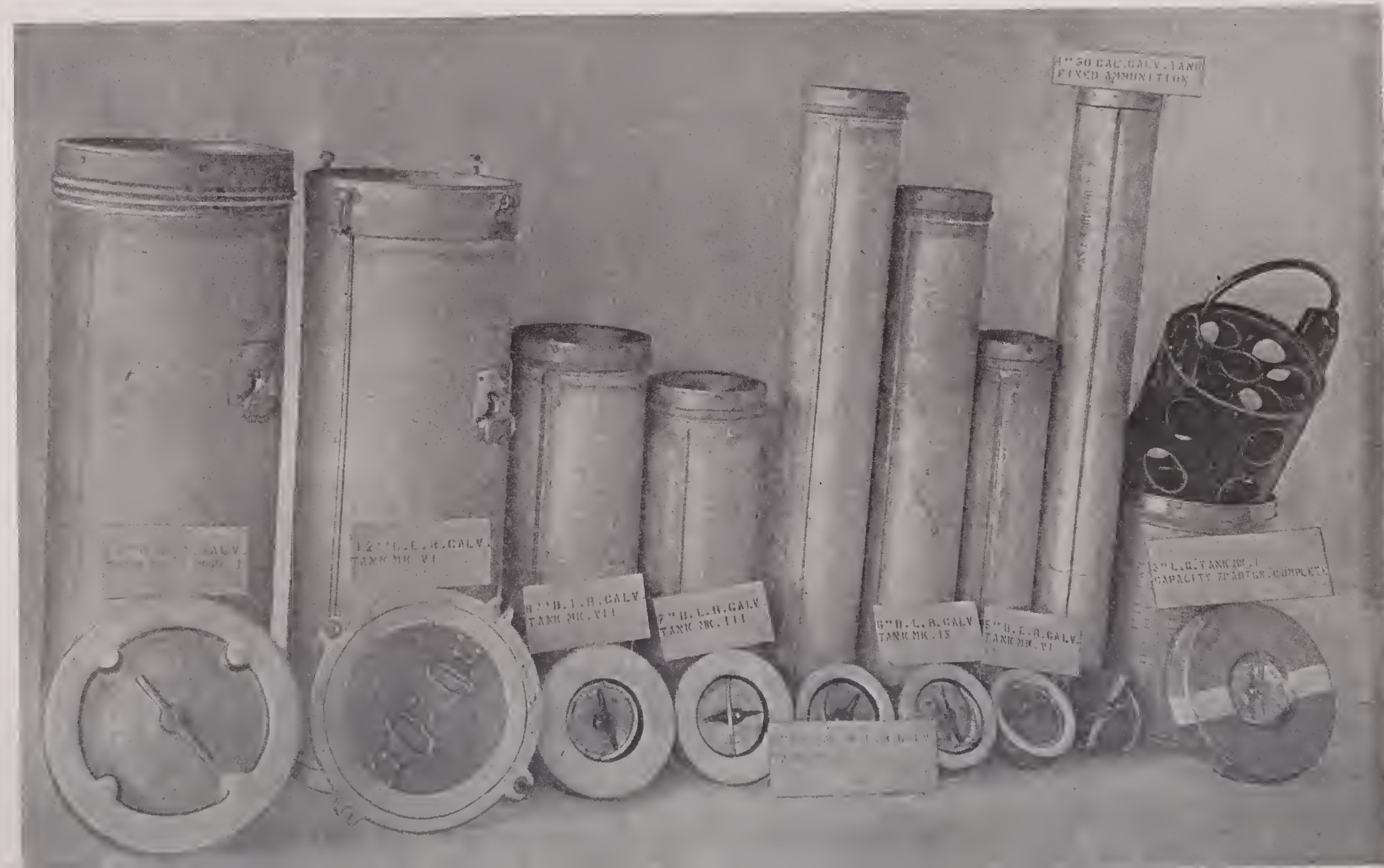


Fig. 5.

DESIGNS OF POWDER TANKS.

TYPES OF CARTRIDGE TANKS.



TYPES OF CARTRIDGE TANKS.

682. The design of all tanks is such as to contain the charge with the least amount of waste space, hence the cylindrical form has been adopted, as requiring the least amount of metal, the smallest closure, and, except in case of rack stowage, the least stowage space. The inside dimensions of a powder tank should be such that it will be a gauge for the charge, so that charges which fit the tank will fit the guns. To provide for uniformity in loading, it is considered desirable to have the total length of charge bear a fixed relation to the length of chamber. The length of the several sections when placed end to end, as they would be in the gun, should be about two inches less than the distance from the mushroom face to the base of the projectile when seated. This condition is not obtained for all guns in service, due to the design of old tanks.

683. In order to sustain a good rate of fire it is necessary to have the tanks so designed that the covers can be quickly and easily removed. As it is forbidden by regulations to open more than one charge per gun at a time in a magazine or gun compartment during firing, or to loosen a cover so that more than one charge is exposed during firing, it is desirable to have the least number of men employed in keeping the rate of supply equal to the rate of fire. Special wrenches are provided for the removal of the tank covers.

684. Special handling facilities are provided for lifting and transporting powder tanks, either as a bail fitted to the cover, or as handles on the sides. The handling arrangements should be such that no injury will result in developing leaks, and in all cases the bail or handles should be fitted to the strong part of the tank. Handles fitted to the sides do not fulfil this condition, and will not be provided in the future; instead, slings around the top ring will be used.

685. Tanks are stowed in tiers, either in racks or loose stacked. When loose stacked they must be designed so that the stronger parts will take the weight and so that projections do not interfere. Each tank must be so strong that the weight of those piled on top of it will not deform it sufficiently to cause a leak or jam the cover. When tanks are stowed in racks these conditions do not have to be fulfilled.

686. The size of the individual tank should be such that it will contain the largest fraction of the charge and still not be too cumbersome for easy handling. Up to 8-inch the entire charge is contained in one tank, from 8-inch to 16-inch two tanks are required per charge; for 16″/45 two and one-half tanks are required, and for 16″/50 three tanks are required. A tank weighing loaded three hundred pounds is considered to be a maximum for ease in handling. The fewer tanks to be used means the fewer closures and the fewer opportunities for leaks and chances for deterioration of the powder.

687. As a protection for the powder, the interior of a tank must be neutral, clean, dry, and free from dirt. Sheet-steel tanks are painted on the inside with non-acid paint. Tanks constructed by soldering or sweating are treated with alkali water and thoroughly cleaned with fresh water. As a protection to the ignition pad, a sheet of clean manila paper is placed in the bottom of the tank.

Plate VI shows the general features of powder tanks. As there are many types in service no attempt will be made to describe any in particular.

Fuses.

688. **A fuse** is a device which, when exploded by the action of its mechanism, ignites or detonates the burster charge of the projectile either on or after impact, or in flight. A fuse functioning on impact is a "*percussion*" *fuse;* one functioning after a definite time in flight by its own internal action is a "*time*" *fuse.* Certain types combine the features of both these and are called "*time percussion*" *fuses.*

689. A fuse must (a) be safe in assembling, handling, transporting, loading and firing, (b) not function prematurely, (c) be positive in its action, (d) not be subject to deterioration in storage.

690. A fuse is said to be *armed* when, by the action of its mechanism, the firing point is in a position to impinge on the cap with any forward motion of the plunger.

691. The "*set-back*" is the action which occurs when the projectile starts to move. That is, the inertia in a movable part will cause it to lag behind the fuse stock which is rigidly attached to the projectile by the fuse threads. The "*creep*" is the action of a

movable part inside the fuse due to the retardation of the projectile in flight from air resistance. That is, the part will tend to move forward, as the air resistance does not affect it.

692. Fuses as originally used in spherical projectiles were "time," or "concussion" fuses. No entirely satisfactory "percussion" fuses were ever developed prior to the use of rifled guns and elongated projectiles.

693. The oldest form of time fuse was a piece of "fusee" or "slow match." This was followed by a wooden fuse forced into the opening in the shot, containing a compressed black powder charge, which was ignited by the blast of the gun and when burned down to the end spit through an opening into the burster charge and exploded the projectile. The wooden fuse was cut off or pierced along its length to fix the time of burning. In later developments, metal cases were substituted but the principles involved were the same. In a concussion fuse, an inflammable composition was ignited on discharge of the gun and, on impact, by some contrivance, the flame was admitted to the burster charge. The contrivances used were glass tubes, zinc tubes, which when heated by the burning powder inside would break off on impact, or by plaster of paris tubes. Due to the fact that a spherical projectile would strike on any point of its surface, percussion fuses did not operate satisfactorily, though tried in many forms. In one type three distinct double-ended plungers were used with their axes perpendicular to each other. The plunger, whose axis was in line on impact, was arranged to strike a fulminate composition. The plungers were held in place during flight by copper shear wires.

694. On the introduction of rifled guns and elongated projectiles, the troubles with percussion fuses were largely eliminated, and as the projectile always struck point first, the use of the motion of a plunger striking a cap on impact was made possible. The adaptation of the rotation of the projectile to additional safety features marked the further advancement in the design of fuses. With the modern use of high explosives a further change was required in providing a detonating element and in producing a delay action feature.

695. All percussion fuses act by the forward motion of a plunger in the fuse body, caused by the sudden arresting of the motion of the projectile. The plunger carrying the firing point

strikes a primer cap; or else, carrying the primer cap, causes it to impinge on the firing point which is held rigidly in place in the fuse body.

696. A "percussion fuse" may be either an *ignition fuse* for exploding a black-powder charge or a *detonating fuse* for detonating a high-explosive charge. A percussion fuse may be designed to fit into the base or to fit the nose of the projectile.

697. In the simpler and older types of percussion fuses, the plunger was held in a safe position by split rings or by shear pins. The action of "set-back" on discharge caused the plunger to shear the pin or to ride over the split rings and then be in a position to move forward on impact. This was the first form of safety device. It proved insufficient for complete safety as one blow would arm the fuse. To obviate this difficulty advantage was taken of the rotation of the projectile to provide centrifugal safety locks on the plunger to keep the firing point away from the primer cap until the projectile had attained sufficient rotational speed in its passage down the bore. Refinements were then added to prevent complete arming until the projectile had left the muzzle. A premature discharge in the bore would cause a tremendous amount of damage.

698. The conditions for safety may be summarized as follows:

(a) Fuse must not be armed when dropped or joggled.

(b) Fuse must not function on set-back.

(c) Fuse must not function in bore.

(d) Fuse must not function prematurely in flight.

699. The centrifugal weights are held in place by small springs and are usually duplicated so that a knock on either side will only dislodge one and even then it will be replaced at once by the spring. The motion of "set-back" tends to carry the firing point away from the primer cap so no difficulty is found in this respect. The weights of the centrifugal parts are so designed or the relative motion of the parts so prevented that the final arming is not effected as long as the projectile is subjected to the accelerating force.

700. There is a tendency for the plunger to creep during the flight, as it is not subject to the same retardation as the projectile due to the air resistance. This will cause the plunger to move forward and leave the firing pin in contact with the primer cap.

A light spring forward of the plunger is introduced to obviate this difficulty.

701. The Semple centrifugal plunger illustrates the safety features as now found in fuses. This mechanism is used by many fuse makers for a number of governments. It is patented in many countries. As certain other features of our fuses are confidential the plunger action only will be explained. The mechanism, Plate VII, consists of the firing pin 2, plunger body 1, safety pins 3, safety-pin springs 4, firing-pin axis 5 and the creep spring 6. In the safety position Fig. 1 the safety pins are pressed against the firing pin in its safe position, by the small safety-pin springs 3. A side blow would dislodge only one of them so that the fuse is safe from side impact. The fuse is safe from drop for the firing point is housed in the plunger. When rotated the safety pins are forced out against the action of their springs and the firing pin for the same reason rotates on its axis, bringing the firing point into the armed position. The inertia in the firing pin will cause it to lag during the acceleration of the projectile until the projectile leaves the gun, at which time the firing pin assumes the position shown in Figs. 2 and 3. Before assembling the plungers in the fuses they are tested in a clutch driven by a motor and must arm at a predetermined number of revolutions, varying from 1300 to 3000 R. P. M.

702. Certain detonating percussion fuses are provided with a delay action element so as to permit the projectile to pierce and detonate behind armor. Some ignition fuses are so designed as to function on graze for land work or on water impact. The fuse stocks are made in two sizes, one for minor-caliber projectiles, 3-inch and below, and the other for medium-caliber projectiles, 4- and 5-inch. Detonator fuses are used for 6-inch and above.

703. The time fuse depends on the burning interval of a specially prepared slow burning powder compressed into a groove or ring. This composition is carefully mixed to render it as uniform as possible, in order that equal lengths will be consumed in equal time intervals. When the powder has burned to the end of its train, the flame ignites the fuse magazine charge and then the burster charge, exploding the projectile instantly. The setting of the fuse determines the length of powder train which will burn, hence the time interval to the burst. Formerly, time fuses were

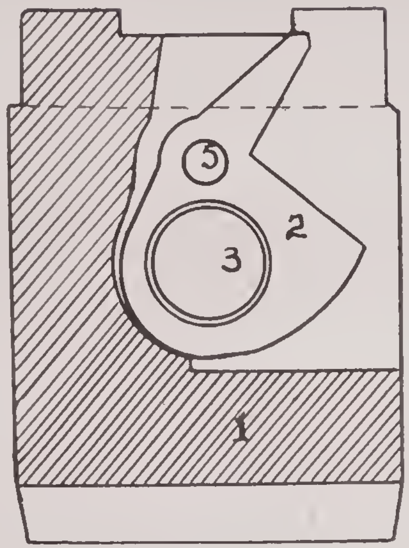


FIG. 1.

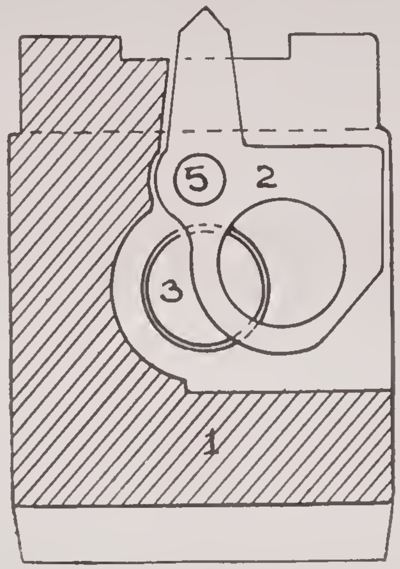


FIG. 2.

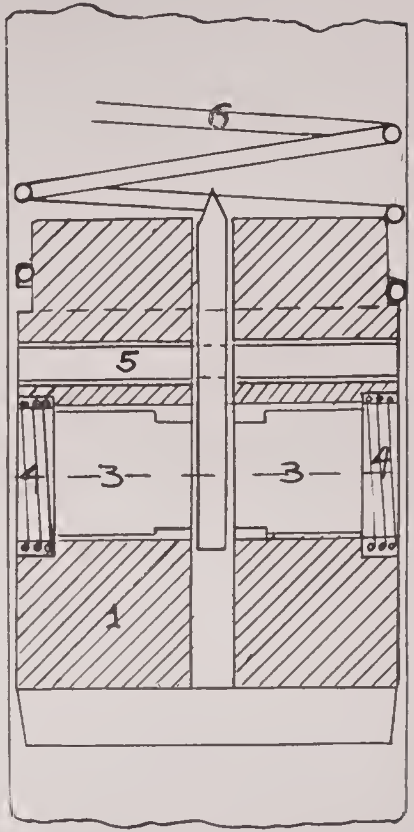


FIG. 3.

1. Plunger. 2. Firing Pin. 3. Safety Pins. 4. Safety-Pin Springs. 5. Safety-Pin Axis. 6. Creep Spring.

SEMPLE CENTRIFUGAL PLUNGER.

ignited by the flame from the powder charge of the gun, as it came in contact with the exposed powder train, which was cut for the desired time interval. In the present high-powered guns, it has been necessary to use a primer action. The powder train is ignited by the flame from a primer cap which is struck by the action of the plunger moved either by set-back on discharge of the gun or by the rotation of the projectile.

704. The following conditions affect the uniformity of action in time fuses with the powder trains:

(a) Age of fuse.
(b) Hygroscopic condition due to storage.
(c) Barometer pressure.

Old compositions burn more slowly than new ones due to chemical changes in the constitutents of the composition.

Black powder is very hygroscopic. Fuses stored in a damp atmosphere will permit the composition to take up moisture and cause it to burn slowly. If they are stored in a warm atmosphere, the composition will dry out and burn faster.

Increased atmosphere pressure causes the powder train to burn faster, while decreased pressure causes it to burn slower. This change in rate of burning has become a matter of prime importance in anti-aircraft firings. There are two reasons given for the change in rate of burning with change in atmospheric pressure. Each layer in the train is ignited by having its temperature raised by the gases of combustion of the layers above it. With decreased atmospheric pressure the gases expand more freely and consequently are not in such close contact and, furthermore, by the increased expansion cool more rapidly, causing a decreased rate of burning.

The size of the projectile affects the rate of burning in that the loss of velocity for larger projectiles is less; hence the change in pressure on the fuse is less and the powder train burns quicker.

On account of these disadvantages clockwork time fuses are being adopted but their details are not published.

The Frankford Arsenal 21-second time percussion fuse is the one generally used for shrapnel. An adaptation, the Scovill time fuse, having the time element only is used for anti-aircraft work.

705. Frankford Arsenal 21-second combination fuse.—This fuse is shown in Plate VIII. Most of the parts are made of

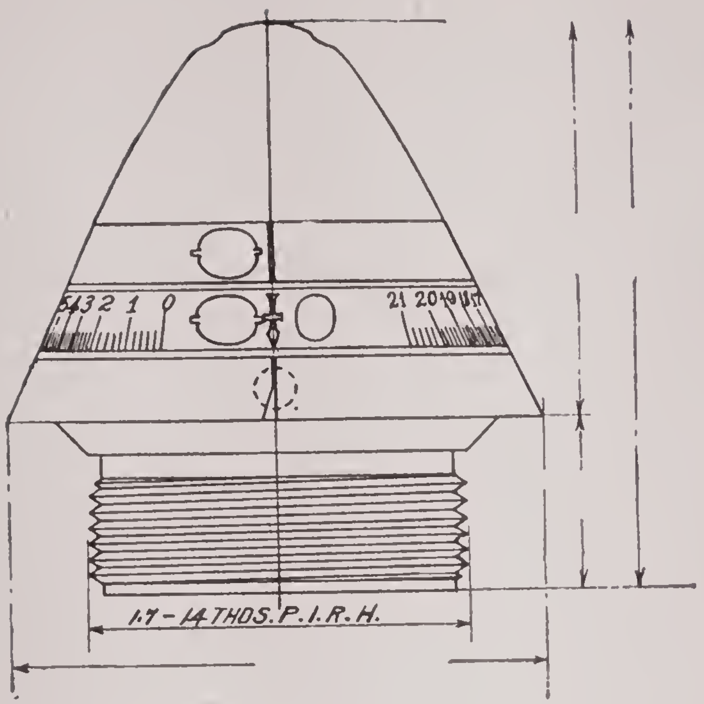


FIG. 1.—Exterior.

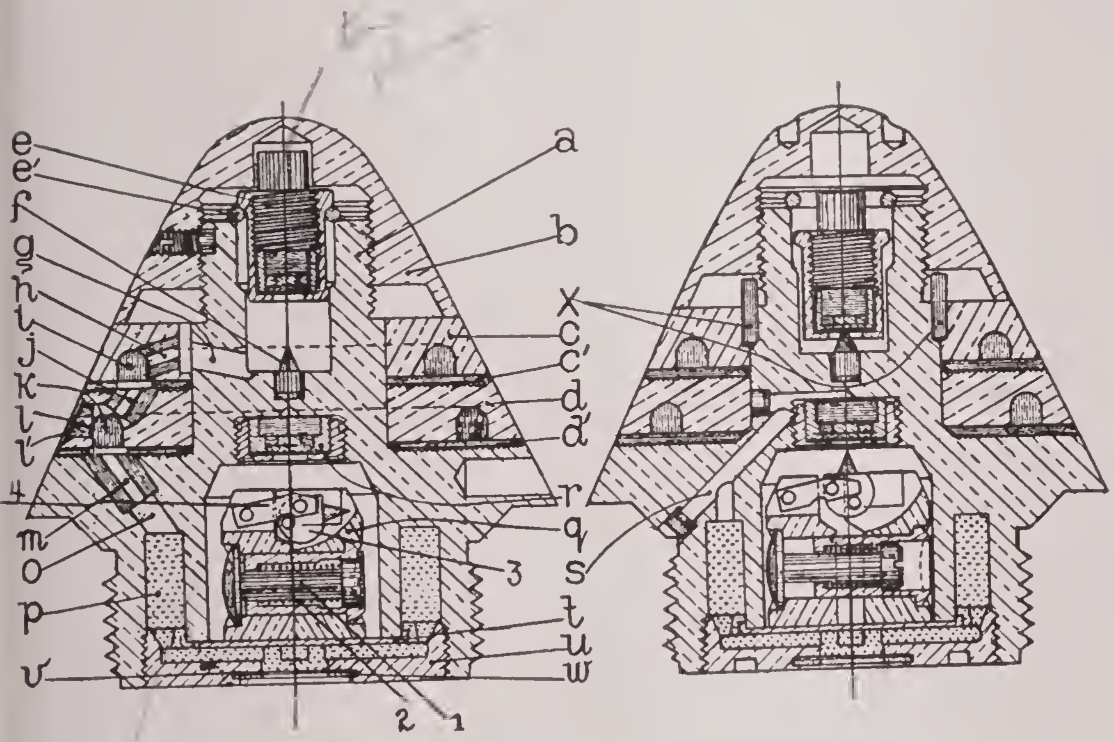


FIG. 2.—Before Arming.

FIG. 3.—After Arming.

FRANKFORD ARSENAL 21-SECOND COMBINATION FUSE.

bronze. There are two time-train rings, *c* and *d,* and an annular horseshoe-shaped groove is milled in the lower face of each ring. Meal powder is compressed into these grooves under a pressure of 70,000 pounds per square inch, forming a time train, the total length of which is 7 inches.

The time element of this fuse is composed principally of the following parts: the *time-plunger e,* the *split-ring spring e',* the *firing-pin f,* the *vent g* leading to the *upper time train i,* the compressed *powder pellet h,* the *lower time train k,* the *compressed powder pellet m,* in the *vent o,* leading to the *powder magazine p.*

The upper ring *c* is prevented from rotating by the *pins x.*

The vent *g* is drilled through the walls of the time-plunger chamber, and is exactly opposite a hole in the inner surface of the upper time train leading to the end of the train from which the direction of burning is anti-clockwise. The hole *j* is drilled through the upper face of the lower time-train ring *d,* to the end of the lower time-train groove from which the direction of burning is clockwise.

The lower time-train ring is movable, and is graduated on its outer edge in a clockwise direction from 0 to 21, each full division corresponding to one second of time of burning in flight; these divisions are subdivided into five equal parts, each corresponding to one-fifth second. A radial hole is provided in the lower ring for a pin to be used in setting the fuse. An arrow on the lower flange of the fuse stock is the datum line for settings.

The vent *o* is drilled through the flange of the fuse stock to the powder magazine *p,* and leads to the same end of the lower time train as the vent *j*—that end from which the direction of burning is clockwise when the fuse is at its "zero" setting.

The action of the fuse as a time fuse is as follows: Assume first the "zero" setting as shown in the figure. The time plunger, a ring-resistance plunger, arms on the stock of firing. The flame from the primer passes out through the vent *g,* igniting the pellet *h,* to the end of the upper time train *i;* and down through the vent *j,* to the end of the lower time train *k;* and thence through the vent *o,* to the magazine *p.*

It will be seen that for the "zero" setting of the fuse the origins of both upper and lower train are in juxtaposition. Assume any other setting, say 12 seconds. The vent *j* has now

changed its position with respect to the vent *h*, leading to the beginning of the upper time train, and the vent *o*, leading to the powder magazine *p*, both of which points are fixed by the angle subtended between the "zero" and the 12-second settings. The flame now passes out through the vent *g* and burns along the upper time train in an anti-clockwise direction until the vent *j* is reached, when it passes down to the beginning of the lower train and burns back in a clockwise direction to the position of the vent *o*, whence it is transmitted by the pellet *m* to the magazine *p*.

For the 21-second setting the flame burns the length of both trains. As the trains do not extend all around the fuse, the solid part between the ends of the trains is utilized to obtain a safety setting. When this point, marked *S*, is brought opposite the arrow on the lower flange of the fuse, the vent *j* is covered by the solid metal between the ends of the upper train, and the vent *o* is covered in a similar manner by the lower or movable ring.

The percussion element consists of the *primer r* and the new *centrifugal plunger q*. The plunger is in two parts held together by the *bolt* (1), and *spring* (2). When the fuse attains 2500 revolutions, the plunger opens out and the cross-pin (4) pulls the *point* (3) to an upright position, so that upon impact the plunger will fly forward and the point will strike and explode the primer.

706. Time fuses are covered with thin brass covers held on by soldered strips. These are removed by tearing the strip preparatory to setting the fuse. Rubber covers are provided in case the round is not fired. It is of the greatest importance to keep fuses dry for the reasons given above.

New time fuses require special fuse setters, the details of which are published in pamphlets issued by the Bureau of Ordnance.

Tracers.

707. A tracer is a device fitted on a projectile to make it possible to follow it in flight. There are two kinds, the day tracer for anti-aircraft work and the night tracer for general use. A tracer may be incorporated in the same stock as the base fuse, in which case it is called a *tracer fuse*. However, both are distinct and independent of each other in action.

In a day tracer, a trail of black fluid or smoke is left by allowing the fluid to be thrown out by centrifugal force or by the products of combustion of the tracer compound.

In the night tracer, the illumination is accomplished by means of a highly compressed slow burning composition ignited by a friction element or by a percussion cap. In the former type there is a small air chamber in the mouth of the tracer covered by a metal disk in which is cut a gas port. The cover is connected to the friction element by means of a rod. (Plate IX, Fig. 1.)

708. The action of the tracer is as follows: On explosion of the smokeless-powder charge of the gun, the gas of the charge enters the tracer chamber through the gas port; and, while the projectile remains in the bore of the gun, the gas in the tracer chamber is under high pressure. After the projectile leaves the gun, the pressure on the tracer port being released, the cover of the tracer is forced to the rear by means of the expansion of the gas in the chamber. The forcing of the cover to the rear draws the central rod to the rear and ignites the friction element, which, in turn, ignites the slow-burning composition of the tracer. This composition burns from 12 to 15 seconds, depending upon the design of the tracer.

In the latter type the ignition is effected by the action of a firing pin on the cover acting on a primer cap.

Plate IX shows different types of tracers.

Tracer mixtures are confidential.

Projectiles.

709. The manufacture of projectiles is treated in Chapter XV. As an ammunition detail, the main concern is the loading and fusing of a projectile. The explosives used are high explosives or black powder. The cavity of a projectile must be especially prepared to receive the burster charge by treating it with a coat of non-acid paint; in order that no sensitive combinations may be formed with the explosive used. The burster charge may be of picric acid or one of its compounds, TNT, ammonium nitrate, tetryl, black powder, or combination of any of these. In U. S. Navy projectiles explosive "D," TNT, or black powder is used, all of which are stable under ordinary conditions of storage.

710. The purpose for which a projectile is to be used fixes the kind of burster charge and the type of fuse. The degree of fragmentation is fixed by the character of the burster charge. In armor-piercing projectiles, which are very tough, a high explosive

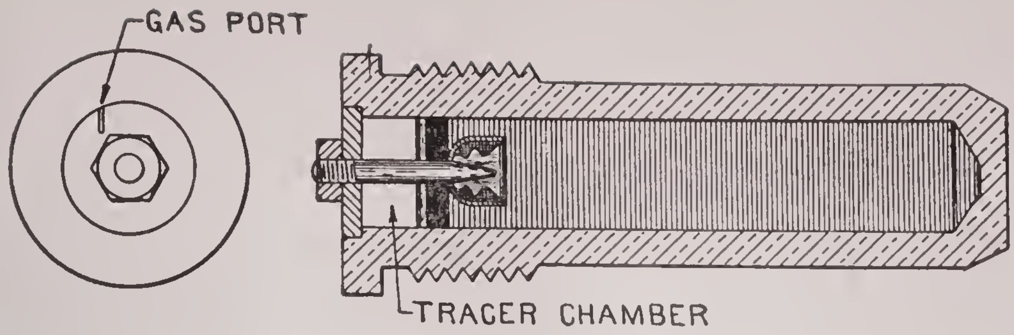


FIG. 1.—Target Tracer for Minor-Caliber Projectiles.

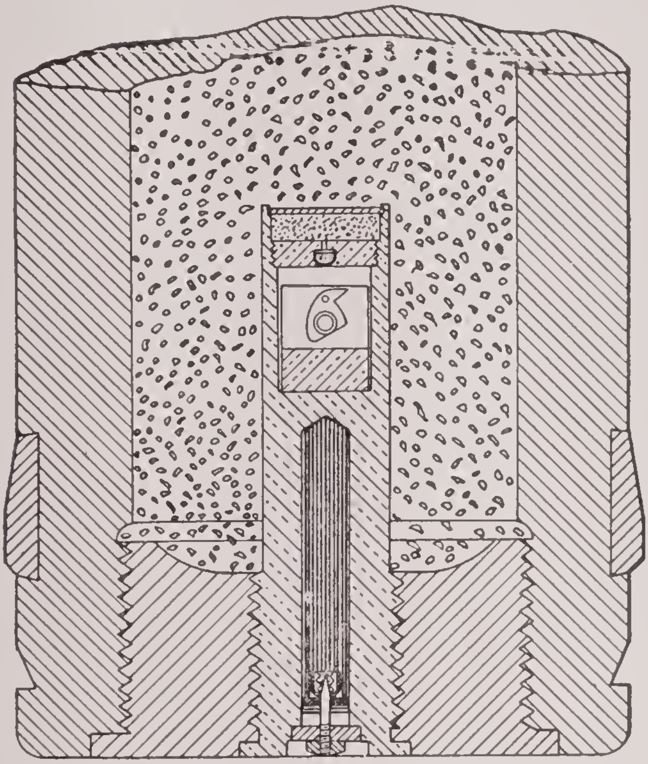


FIG. 2.—Tracer Fuse for Minor-Caliber Projectiles.

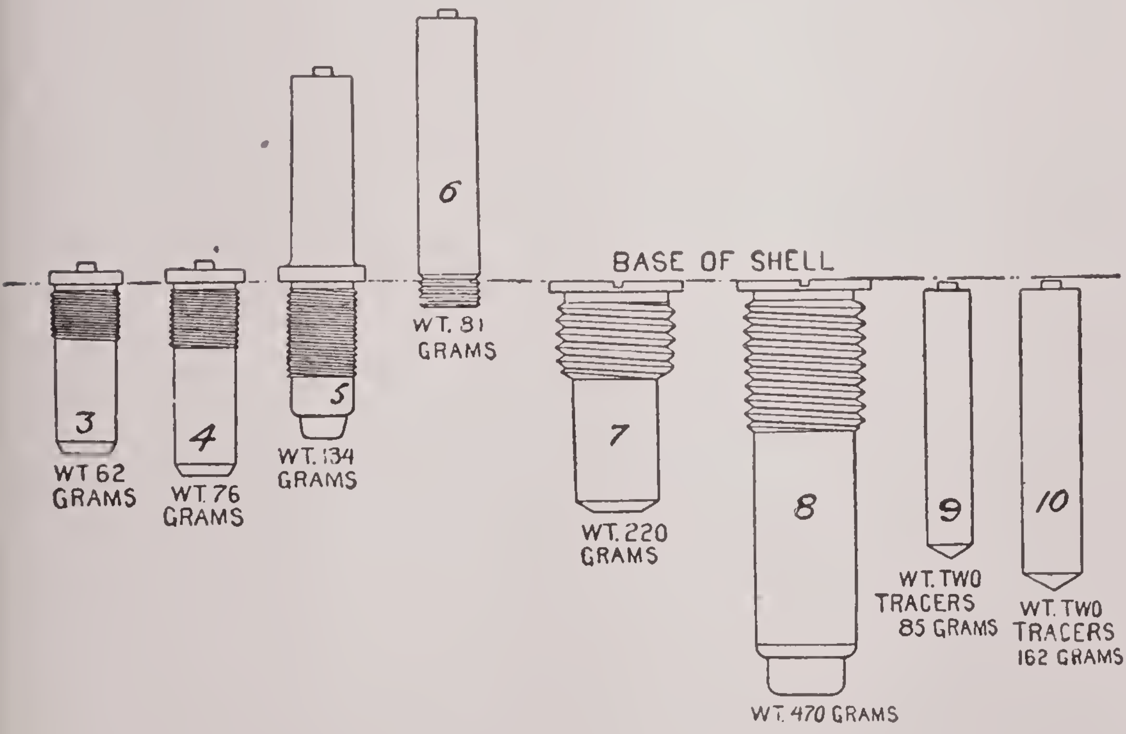


FIG. 3.—Tracers (3, 4, 6, 7, 9 and 10) and Tracer Fuses (5 and 8).

TRACERS AND TRACER FUSES.

is required. In common projectiles, the proper fragmentation is obtained by mixing a high explosive with black powder. The high explosive in this case is not detonated but gives a low-order detonation, that is, the high explosive is consumed by burning rather than by changing instantaneously into the gaseous state. A high explosive in a common projectile, if detonated, would break the metal up into such small pieces that it would not be effective. In Class B projectiles, where the explosive force of a large quantity of high explosive rather than the damage from fragments is desired, TNT is used. In shrapnel and illuminating projectiles, where the object is to discharge the contents of the projectiles, small black-powder charges are used. Flat-nose projectiles are loaded similarly to Class B projectiles.

711. When gas loaded, some of the explosive charge is omitted and replaced with a container either of cotton duck or metal holding the gas mixture. On burst the gas mixture is diffused in the atmosphere. Various kinds are in use, some of a very poisonous nature, but the details of preparation are confidential.

The following table shows the assembly of projectiles:

Projectile.	Designation.	Burster charge.	Fuse.
Armor piercing...	A. P.	Explosive "D."	Delay action detonating.
Common	C.	Black Powder, TNT or "D."	Ignition percussion.
Shrapnel	Shrap.	Black Powder.	Time percussion. (For A. A. time only.)
Illuminating	S. S.	Black Powder.	Time.
Class B..........	Cl. B.	TNT.	Time percussion detonating.
Flat nose.........	F. N.	TNT.	Sensitive percussion detonating.

Any of the above fuses may have a tracer element, or a tracer fitted in the base.

Base plugs are described under the manufacture of projectiles.

Powder Bags.

712. The charges for powder bag guns are prepared by placing the powder in bags made of special silk cloth, sewed with silk thread and laced with a silk cord. The object in using silk instead of a less costly material is to reduce the danger from unconsumed

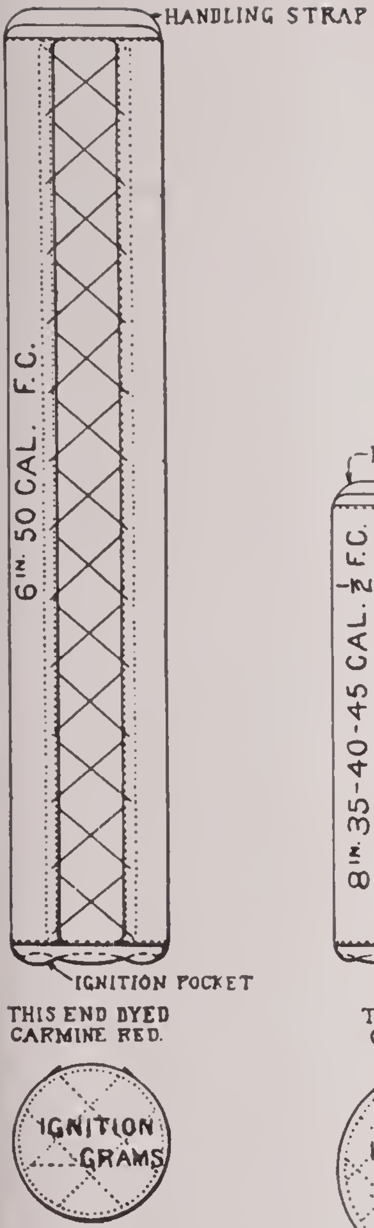


FIG. 1.

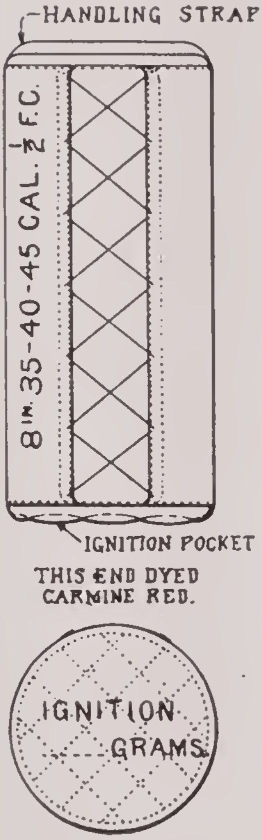


FIG. 2.

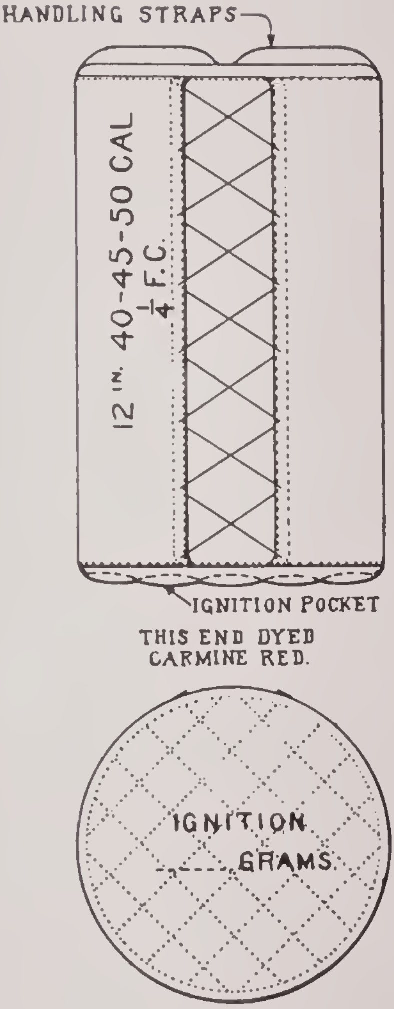


FIG. 3.

CARTRIDGE BAGS.

smoldering residue. There are two weights, light and heavy. The body of the bag is made from the heavy in order to withstand better the necessary handling, permit of tight lacing, hold the required weight and reduce the tearing due from cutting by the edges of the grains. The light weight is used for the ignition ends where it is required to hold no weight and where it is desired to have the flame from the primer burn through readily. Plate X shows the details of powder bags.

713. The following conditions must be fulfilled by powder bag cloth:

(1) Strong enough to stand handling and transportation, especially the wear and tear of movement in tanks due to the motion of the ship.

(2) Close weave to contain the powder, especially if dusty.

(3) Permeability to flash for combustion.

(4) Ability to withstand chemical changes in case of reactions in the powder.

(5) Must be entirely consumed.

(6) Free from acids which may react on the powder.

714. On one end the ignition charge is attached, made by enclosing in a circular bag of thin silk cloth the required amount of black powder, then quilting the sides together to form the ignition pad. The face of this ignition pad, which is to be on the outside, is made from silk cloth previously dyed red. The pad is then sewed to the bottom of the bag. The other end of the bag is fitted with a strap for handling, sewed to the front end with extensions down the side. These straps are strongly made to withstand the required handling in withdrawing the bag from the tank and in the successive steps in loading the gun. In order to make a compact package, two flaps with eyeholes at intervals are sewed down the side at such a distance apart that when laced together by a silk cord enough space will remain to permit of taking up any slack which may result from further shaking down of the charge in service or from any stretch in the material.

715. Distance pieces and wads.—Formerly powder bags were used with case ammunition, the bags, fitted with an ignition pad, being loaded with the powder charge and assembled in the cartridge case. The space between the bag and the projectile was filled with excelsior. With the advent of the ignition primer the

interior bag has been omitted, and cardboard disks and distance pieces are now used in place of excelsior. Disks are cut slightly larger than the diameter of the case and slit down from the edge to the center. Distance pieces are made by crossing and locking four pieces of cardboard in a manner similar to that used in commercial life for crates. The distance pieces are cut to the desired length depending on the amount of powder used. Felt wads, cut to the size of the case, are used in place of distance pieces when the charge fits the case snugly, or when saluting charges are prepared.

Mouth Plugs.

716. With separate case ammunition, it was formerly the practice to seal the case with a brass mouth cup. This was in the form of a brass bowl, the sides of which fitted inside of the case. The object in its use was twofold, first to form a gas seal in the case to prevent escape of the gases past the rotating band, also to keep gases from breaking cases by outside pressure on the case, before the projectile started to engrave the band in the grooves, and, second, to make the case an air-tight container for the powder charge. It has been shown that the gas escape is insufficient to require this form of seal and as the brass mouth cup had a tendency to break up and boomerang back, so as to endanger personnel, cork plugs have been substituted, and these effectively protect the powder.

Assembly of Ammunition.

717. Ammunition details are received at ammunition depots from the manufacturers after proof and stored until required for assembly for issue to the service. When orders are received for the preparation of ammunition, the projectiles are loaded and fused, the powder charges assembled, the ammunition packed and marked and prepared for delivery to the ship, in such a condition that no further work is required on it.

718. Projectiles are loaded as a separate operation. Each one is cleaned, gauged, inspected, and then loaded with the proper explosive. Black powder or the mixed filler is loaded in loosely, explosive " D " is loaded under pressure in hydraulic presses and TNT is loaded either loosely, under pressure, or in the cast

form. After the explosive is loaded the projectiles are removed to a separate room where the fuses are carefully assembled and the projectiles are then painted to show the type of explosive. The loading of shrapnel is a special operation treated under Projectiles.

Projectiles for bag guns, when issued to the service, have special grommets fitted over their rotating bands. These are supplied when the projectiles are delivered by a manufacturer and are intended to prevent burning of the band, knocking it loose, etc. Formerly, they were made of fiber, but the recent design is a canvas belt with a rope grommet abaft the band, the whole being held in place by a marline lashing.

719. In assembling case ammunition the cases are inspected, cleaned, gauged and then the primer is inserted. Case percussion primers are forced into place by hand or machine presses and case ignition primers are screwed into place. Care is taken to see that the primer has the proper seating, neither projecting nor inset too far. The predetermined weight of powder is then weighed out on carefully checked scales and poured into the case. A wad is then forced in to keep the powder in position around the primer, a distance piece is then placed on top of the wad and another wad is placed on top of the distance piece. The case is then placed in a press, the base of the loaded and fused projectile is entered in the mouth of the case and forced in until the rear of the rotating band takes up against the mouth of the case. The cartridges are then packed in containers with great care to obviate any movements in transit or possibility of damage to the nose fuse, if of that type.

720. In preparing bag ammunition the ignition ends are prepared first and quilted in special sewing machines using bronze needles.

The bags are manufactured for each index of powder as required, as the weights of charge vary with the different indexes. The powder is weighed out, dumped loosely in the bag and the lacing passed. The bag is then rolled a number of times, the lacing tightened and secured and the bag gauged for size, then placed ignition end down on a clean sheet of paper in the powder tank. The tanks, when marked to show the contents, are then ready for delivery.

POWDER CHARGE (STACKED GRAINS), FOR 14″ 50-CALIBER GUNS.

Stacked Charges.

721. There are several forms of stacking machines in use, all, however, working on the principle of upending the grains and passing them through apertures and laying them on end on a plate. The grains are then passed along, scooped together in one layer and moved over a cylinder which is covered by a brass plate. When the layer is in position the plate is pulled out, the layer drops down on the one below it and is then forced down the cylinder until there is space for the next layer. When the cylinder has the required number of layers a bag is pulled over it, the cylinder withdrawn and the bag laced and sewed up. Plate XI shows a stacked charge.

Marking of Ammunition.

722. All ammunition is carefully marked or tagged to identify it. Tags are placed in the powder charge, the powder bags are stenciled, projectiles are painted in colors, ammunition boxes and powder tanks are both painted in colors and stenciled.

These markings are self-explanatory, except the colorings used. By means of the markings information is given as to the caliber of gun for which made, weight of total charge, weights of individual fractions of charge, weight of ignition charge, index number of powder, depot from which shipped, initials of weighers, gaugers, checkers, and inspectors, date put up, standard I. V., and any other information of value.

The colors used on projectiles and boxes show the type of projectile, kind of burster charge, type of fuse, weight, whether or not fitted with tracer, and any other necessary or valuable information.

The details of marking are given in a Bureau of Ordnance pamphlet where the method and details of the information to be given are laid down. These instructions are changed from time to time as found necessary.

PART II.

Section I.—Ammunition Stowage and Supply.

723. With the exception of detonators and pyrotechnic material, all ammunition, of whatever character, is stowed in specially constructed stowage spaces or rooms set apart for that purpose alone. Ready service magazines are provided near the guns for emergency use. Projectiles for broadside guns may be stowed in bins in the compartment or passageway near the foot of the broadside hoists. Turrets may have projectiles stowed outside of the projectile rooms either in the turret or below the turret floor. In the more recent designs, no turret projectile rooms are required, as the projectiles are stowed in the barbette (see Chapter X, Plate III).

724. In the older battleships the magazines are placed in groups, forward and aft, connected by wing passages and ammunition passages, which are useful in transporting ammunition from one group to the other in case a turret should become disabled. In the recent designs of all big gun ships, the location is more complicated. Where there are more than four turrets the magazines are in three groups, and where there are four turrets they are in two groups, one forward and one aft, without direct communication.

The simplest and surest solution would be to install a magazine and projectile room directly under the guns it would serve regardless of caliber, with the hoists leading directly up to the guns. This would involve placing a line of magazines along each side of the ship, adjacent to machinery spaces. This solution is not feasible as the rooms would be too near sources of heat and also the space is required for other purposes. This result is obtained for turret guns, however, as the handling of large charges and projectiles, obviously, must be reduced to the minimum. In addition, the space below turrets is available for division into ammunition spaces.

With broadside guns, however, the magazines and projectile rooms are grouped forward and aft, requiring transportation of the less weighty charges to the base of each broadside hoist, either below decks or above decks.

725. The magazine spaces are on the upper and lower platform decks, which places them below the protective deck for security.

They are placed inboard as a further protection in case the skin is pierced, to reduce the chances of an internal explosion. The projectiles for main battery guns for the first all big gun ships and a part of the powder are stored on the upper platform deck in ammunition rooms leading off the handling rooms, and the remainder of the powder in compartments directly below the handling room on the lower platform deck. In later designs turret projectile rooms are dispensed with as noted above. The ammunition for broadside guns is stowed on the lower platform deck, with the rooms communicating with ammunition passages or handling rooms in which the hoists are placed. Conveyors are used to transport the ammunition to the bases of the hoists. In certain designs it has been necessary to handle the broadside ammunition in two stages, bringing it up from the forward and after groups to the third deck and transporting it by conveyor to hoists which serve the individual guns.

726. Adjacent turrets have their handling rooms connected for the interchange of ammunition. To get ammunition from a forward to an after handling room it is necessary to use the passages on the third deck by hoisting ammunition up special hatches and transporting it along the deck with overhead trolleys.

727. Special rooms are arranged for torpedo war heads, saluting charges and small-arms ammunition.

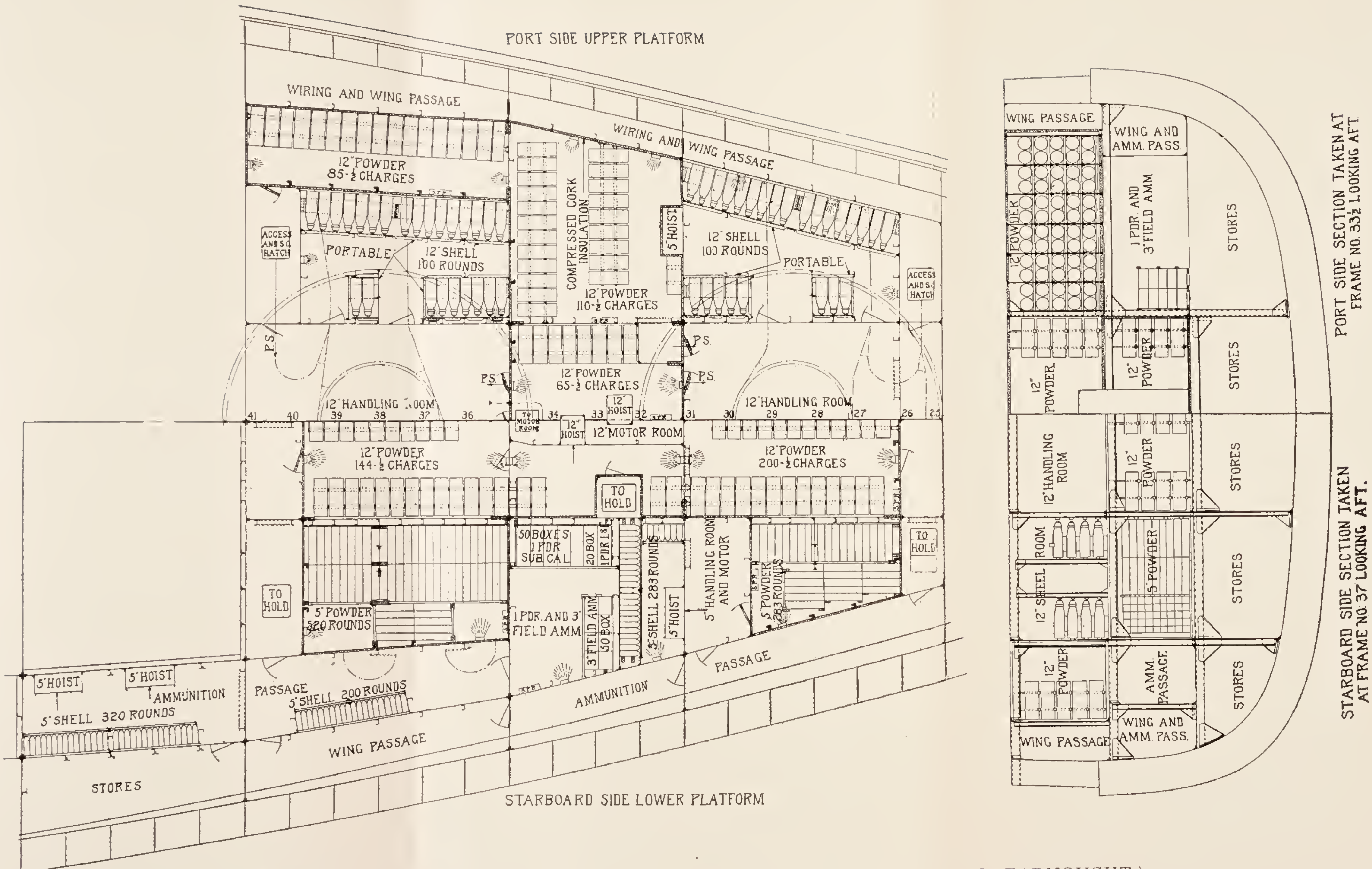
728. Plate XII shows the arrangements of ammunition spaces on a modern battleship. Plate XIII shows the method of stowing projectiles. Plate XIV shows a broadside powder tank stowage arrangement.

The ammunition rooms of other ships are arranged in two groups forward and aft with hoist adjacent, thus requiring the transportation of the ammunition on deck. In general they follow the designs for battleships. Destroyers follow in general the same arrangement as is found on board larger ships. Submarines have special stowage arrangements due to lack of space and small quantities carried.

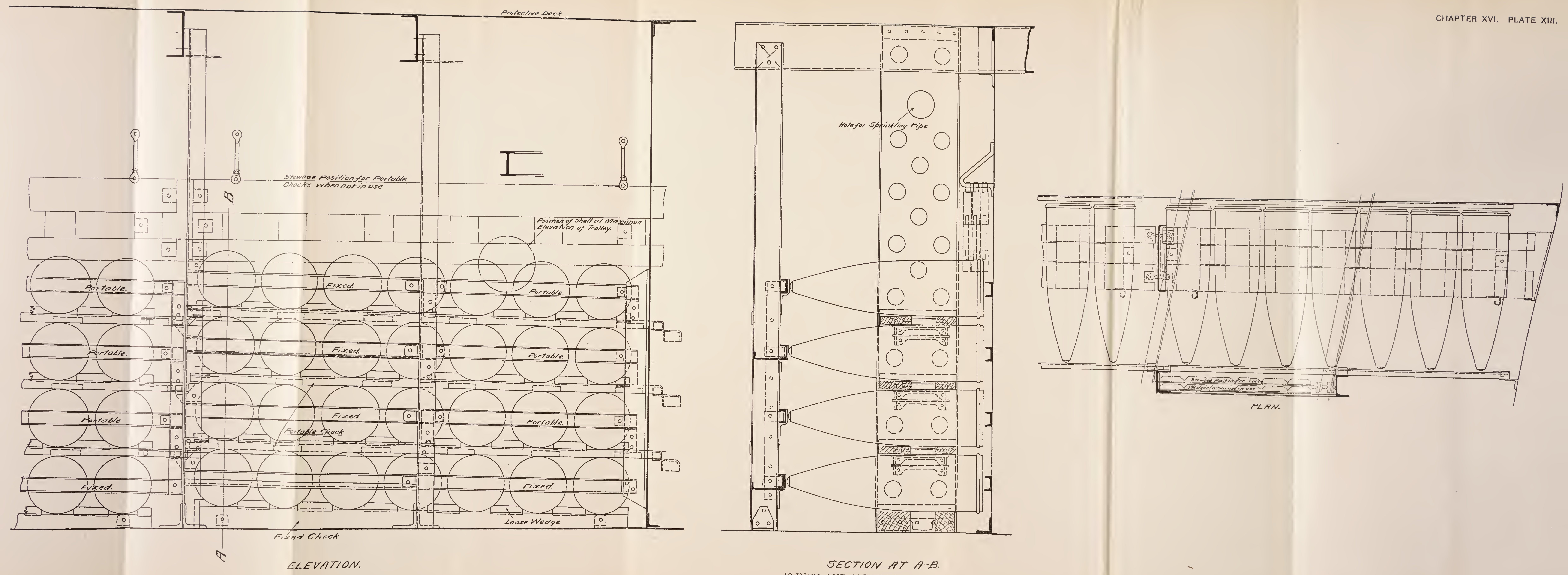
Flooding.

729. Ammunition rooms require special flooding, ventilating and lighting arrangements.

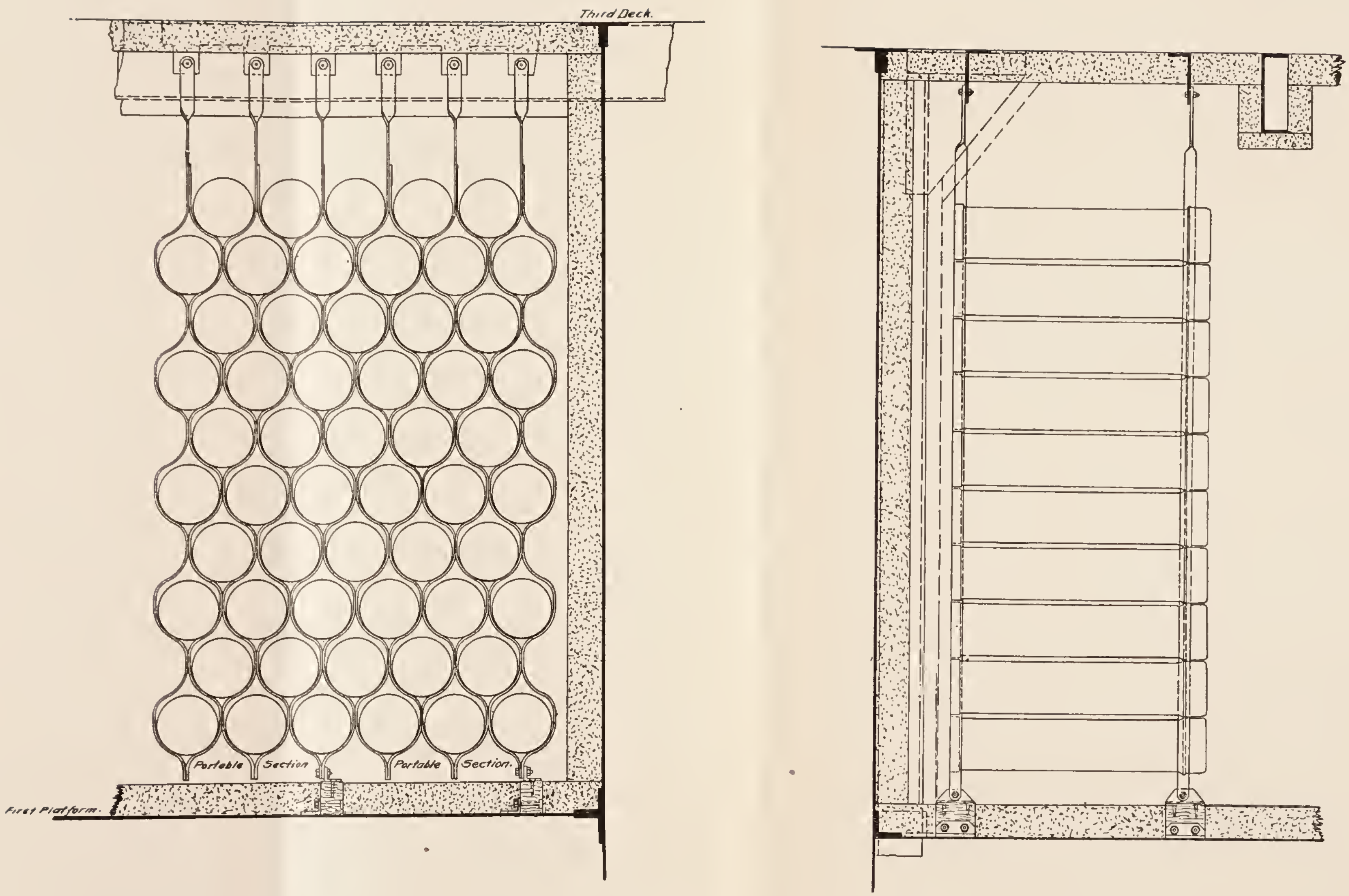
730. The property of an explosive of resisting for a certain length of time, without decomposition, the action of humidity,



AMMUNITION STOWAGE. (UPPER AND LOWER PLATFORM DECK OF A DREADNOUGHT.)



12-INCH AND 14-INCH SHELL STOWAGE.



5-INCH POWDER-TANK STOWAGE.

heat and other elements which tend to cause it to decompose, is called its *chemical stability* (see paragraph 46). To prevent damage from an explosion from this loss of chemical stability, especially in the event of a fire, flooding arrangements are provided aboard ship. In order to conform to the requirements for water-tight integrity, and to provide for flooding, all ammunition rooms are water-tight compartments. Arrangements are made for admitting sea water to each room or compartment where ammunition is stowed. Those above the water-line have pipes leading from the fire main; those below have pipes leading from sea valves. Where the pipe has one large opening it is called a "flood pipe." Where the pipe has many small openings on the upper side and is suspended across the top of the powder or projectile bin, it is called a "sprinkler pipe." In recent designs, ammunition compartments are fitted with both types. Sprinkler pipes are also fitted over gun-loading positions in turrets, over powder-loading positions in handling rooms, and over projectile bins when located in passageways. Sprinkler holes are not over $\frac{5}{8}$-inch in diameter, and their aggregate area equals 150 per cent of the area of the group control valve. One hole is placed over each tank or case, and if of insufficient size to flood the compartment in the time allowed, additional holes are used. When using both flood and sprinkler pipes sufficient water must flow to fill the compartment in 20 minutes. Where the sprinkler pipe alone is used it must be capable of filling the compartment in one hour. Arrangements are made for sprinkling in dry dock.

731. The flood pipe leading from a sea valve has a flood valve in the magazine, connected by a spindle to the berth deck to permit operating either in the magazine or from the deck above. The spindle passes through a water-tight stuffing box in the deck and ends in a square section in the flood-valve deck plate. A special wrench fitting the square head is required to operate the valve. This wrench is stowed in a locked rack on the bulkhead nearby. Sometimes a hinged cover plate fits over the spindle head secured with a padlock. The latest method is to encase the end of the spindle in a glass-front locked box. The keys are kept with the magazine keys which by naval regulations are kept in the captain's cabin.

732. The flood-valve deck, or the case, is marked with the name and number of the compartments it floods and an arrow indicates the direction in which the valve opens. In addition, specially shaped plates, with red ground, secured to the beam overhead, give the same information.

FIG. 123.

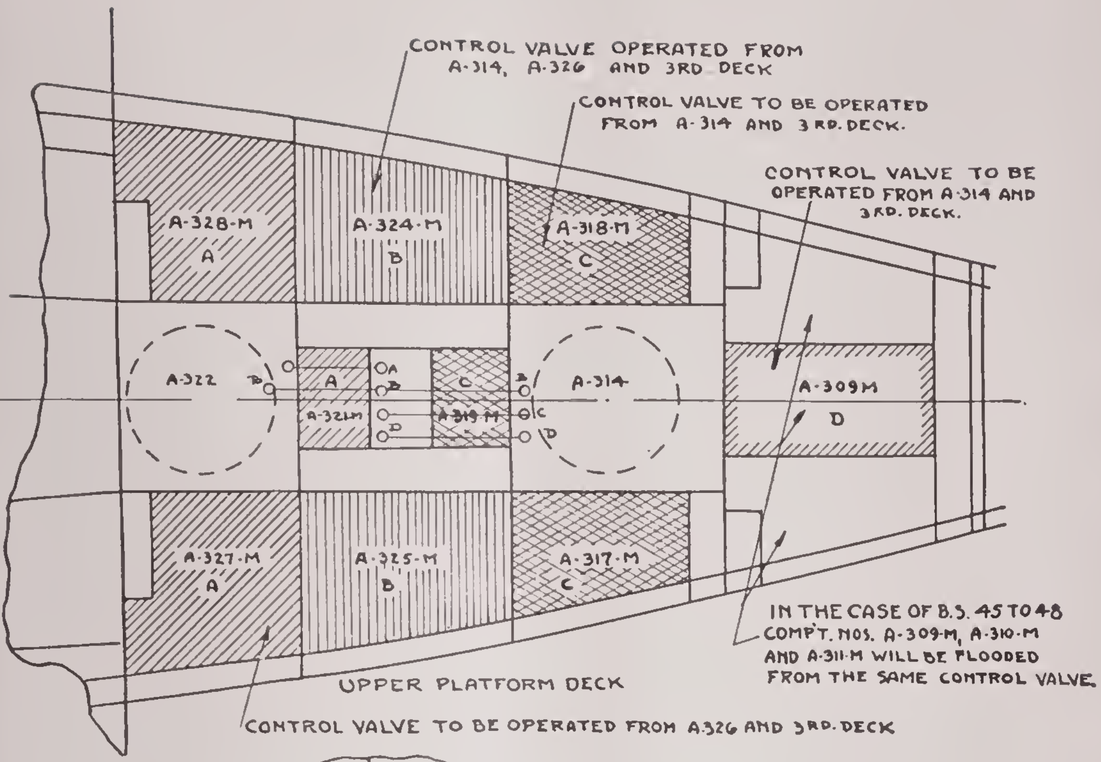
733. In older ships each room is flooded by a separate valve, but in more recent designs the valves are arranged to flood groups of magazines. In this case, the control valve is located in a compartment below the lowest water-tight deck, usually the upper platform deck, and is arranged so that it will flood all rooms in its group by operating the valve, in the handling room which the magazines in question serve, or from the deck above. Each room is fitted with a cut-off valve and a check valve, so that any one or more in a group may be flooded. Plate XV shows the group control flooding arrangements on a new ship. The valve and the rooms it floods are shown, and the different places where the valve may be operated except those on the deck above. Valve openings in flood pipes are fitted with caps and draincocks for testing purposes.

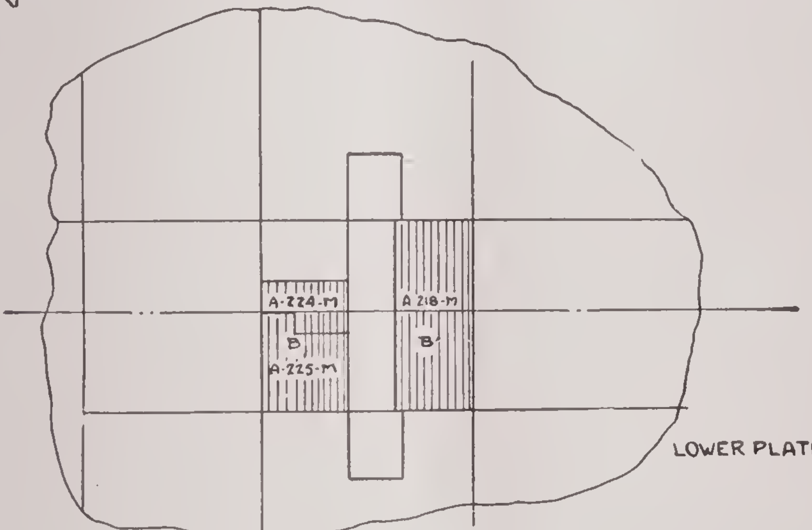
734. As the fire main pressure would be communicated to the bulkheads when a room became filled, it is necessary to provide a relief. This is usually in the form of an exhaust ventilator of such diameter that the flow of water will not permit the pressure in the flooded room to rise above that for which they have been tested.

735. Magazines are not connected to the ship's drainage system direct. Ordinarily, they are drained by portable pumps, or by a drain to the bilge or another compartment, which is connected to the main or secondary drain system.

Cooling and Ventilation.

736. The property of imparting on firing during a greater or less length of time, the velocity and pressure found on acceptance test, is called the "*ballistic stability*" (see paragraph 47) of a





LOWER PLATFORM DECK.

NOTE:- TORPEDO WARHEAD ROOM, A-106-M, SHOULD BE FLOODED BY CONNECTION TO FIREMAIN IN TORPEDO ROOM A-202; THE CUT-OUT VALVE BEING LOCATED IN THE TORPEDO ROOM AND ARRANGED FOR OPERATING AT THE VALVE ONLY.

COMP'TS. OF SIMILAR HATCHINGS ON THIS SHEET FLOODED BY SAME CONTROL VALVE.

-COMP'TS.	LOC. VALVES	B. COMP'TS	LOC. VALVES	C. COMP'TS.	LOC. VALVES	D. COMP'TS.	LOC. VALVES
A-327-M	322	A-324-M	322	A-317-M	314	A-309-M	314
A-328-M	320	A-325-M	314	A-318-M	320		320
A-321-M	3RD. DECK	A-218-M	3RD. DECK	A-319-M	3RD DECK		3RD DECK
	ABOVE 320	A-225-M	ABOVE 320		ABOVE 320		ABOVE 320

GROUP CONTROL FLOODING ARRANGEMENTS.

propellant powder. In order that this property be not impaired, arrangements are made for uniform storage conditions requiring either refrigeration or special ventilation. The life of a smokeless powder is rapidly shortened with an increase of temperature over 90° F. Stabilized powders have better chemical stability than unstabilized powder, resisting changes due to increased temperature better, lasting the same length of time in an atmosphere 20° F. higher. It has been found that a temperature of 70° to 80° F. is suitable for the storage of standard navy smokeless powder. To provide a uniform cool atmosphere in the magazines, various systems of refrigeration have been tried with varying success. However, at the present time, due to the increased stability of our powders, to disadvantages in refrigeration systems, and to improved methods of ventilation, refrigeration is no longer resorted to.

The old systems were of two general types: (1) Using air cooled in a refrigerating box, which served both to cool the magazines, and ventilate them; and (2) using brine pipes in the magazines themselves, which necessitated an independent means of ventilation.

737. The following considerations govern the installation of ventilation systems for magazines:

(a) Attention to water-tight integrity of the ship.

(b) Ventilating pipes so installed that no compartment can be flooded from another through the ventilating pipe.

(c) Ventilating pipes water-tight below the lowest water-tight deck.

(d) Intakes so located as to minimize the possibility of drawing in gas from fires in action.

(e) Natural exhausts fitted to a fixed height above water-line.

(f) Exhausts located inside barbettes.

(g) Intakes fitted to prevent foreign matter entering.

(h) Lower ends of exhausts fitted with check valves to permit egress of water or air, but not permit ingress of either.

(i) Lower ends of supply ducts fitted with water-tight covers for sealing in action.

(j) When ducts pass through a deck or bulkhead, to be fitted with a valve.

(k) Must reduce the temperature from 110° to 90° F. when the outside air is 80° with the usual installation.

738. Most of the above are self-explanatory. The exhaust duct is fitted with a non-return flapper valve and leads up through the deck inside a barbette where it ends in a goose-neck covered with wire mesh. The air escapes then through the turret. When a magazine is flooded, the water escapes in the same way when the compartment is filled and prevents pressure being brought on the bulkheads. The height is fixed above the water-line by the hydrostatic pressure which the compartment is designed to withstand. Magazines do not require ventilation in action so the blowers are stopped and the supply ducts sealed with hinged covers dogged tight.

739. Magazines are insulated with cork composition in order to reduce to the minimum changes in temperature. The insulation is shown on Plate XIV.

740. When the outside temperature is above 90° F. in day time, magazines may be kept cool by running the blowers only at night. It is advisable not to force hot air in, but allow the cool night air to gradually warm up during the day. In case a magazine is so situated that it naturally heats up to a temperature exceeding that of the outside air this will not hold good.

Magazine Lighting.

741. In the older type ships, light boxes are provided inset in the bulkheads, so as to throw light through round double-lens ports in three directions. The boxes are water-tight and open only from the outside of the compartment they illuminate. Each one contains incandescent lamps and a fitting for a candle in case the lamp fails. They are arranged so that the bottom may be covered with water in case the candles are used. Hand electric storage battery lanterns have replaced candles as a secondary system of lighting. They are hung on the bulkheads on brackets. Later ships are fitted with bunker lights recessed in the bulkheads or attached to the bulkhead on the inside of the magazine. These special magazine fixtures have two lamps connected to separate feeders on the magazine circuits which are distinct from other circuits. The control switches are removed from the paths of ammunition handling. They are encased in flame-proof boxes and assembled in groups.

742. Turrets are equipped with the same fixtures as magazines, and are also arranged with duplicate feeders. The auxiliary system in turrets is controlled in the turret officer's booth.

The auxiliary lighting system is so arranged that, when the main circuit fails, the auxiliary circuit will light up.

Supply.

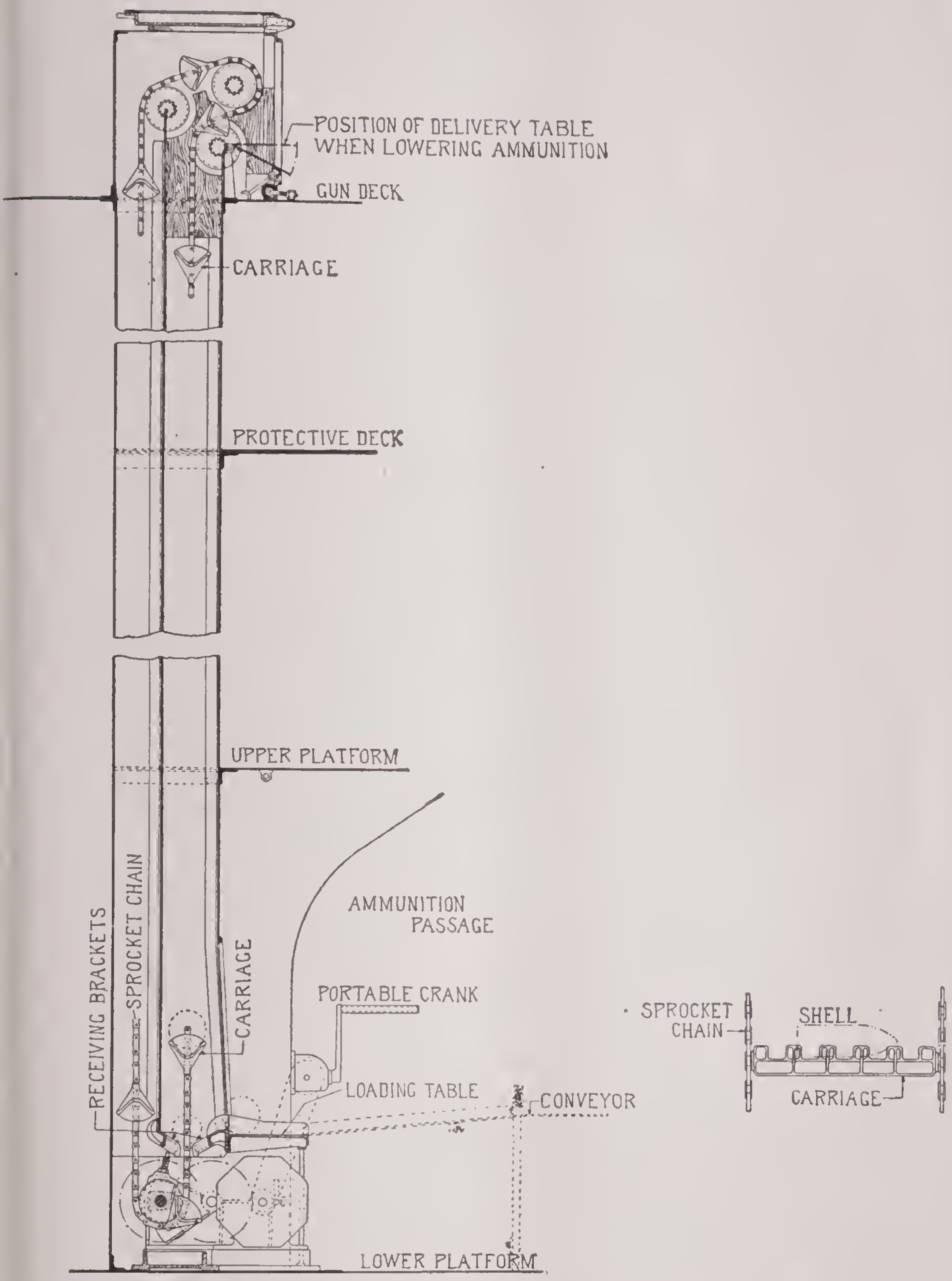
743. The efficient supply of ammunition to the guns is of prime importance, and must be so arranged as to permit a sustained fire without causing a delay at the gun for lack of it, or an excess accumulation with the attendant danger of an explosion initiated by a shot from the enemy.

The problem varies with each individual installation. The design is the best that can be worked out for the individual ship for it must be co-ordinated with other factors. The success will depend on the proper utilization of the equipment provided, so that many losses in time attributed to the equipment may be eliminated with the proper stationing and training of the personnel.

744. The supply in turrets is very simple. Ammunition hoists for turrets are described in Chapter X. The broadside guns are served by chain hoists, motor driven, usually one hoist to two guns. The ammunition is conveyed by conveyor to the foot of the hoist and is delivered near the gun outside of its working circle. Plate XVI shows a broadside hoist without flame-proof doors.

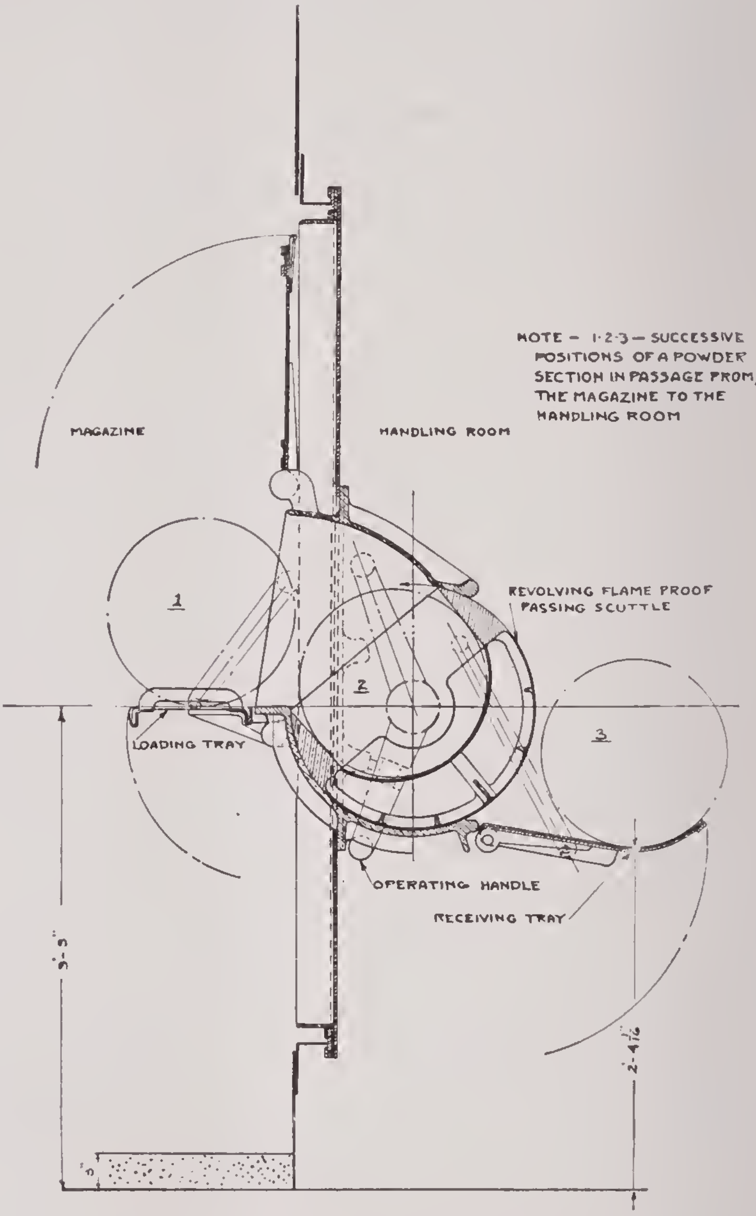
The bottom of this hoist is situated in a broadside handling room or in a passageway. It is covered at the bottom with a flame-proof door. In the older types as the *Connecticut* class, where fore and aft passageways are situated below the protective deck, the ammunition is conveyed to each hoist. In the newer designs where fore and aft communication is impossible below the third deck, it is necessary to have two sets of hoists and conveyors. The ammunition is sent up either forward or aft to the third deck and then distributed by conveyors to the gun hoists. To supply a turret aft from forward or *vice versa,* the same procedure is necessary. Redistribution of ammunition is a slow process and would only be done in a lull in an engagement.

745. Powder paths.—Special precautions are taken to prevent accidents due to flames striking powder as it is being passed along. To prevent the spread of flames, in case the existing arrangements



5-INCH CHAIN AMMUNITION HOIST.

do not prevent this, all compartments through which powder is passed are protected with flame-proof scuttles. Water tanks are also arranged at intervals to permit wetting down a charge in case the sprinkling facilities are not adequate. The old type con-



FLAME PROOF POWDER PASSING SCUTTLE.

FIG. 124.

sisted of a swinging brass flap fitted over the opening in a door, and did not effect the desired result, as it left the way open when a powder charge was being passed from one compartment to another. Fig. 124 shows the latest flame-proof scuttle as installed on recent ships.

BATTERY SHOWING 3″, 4″, and 5″ GUNS ON CIRCLES, VELOCITY SCREENS, AND ARMOR BUTTS.

CHAPTER XVII.

THE PROVING GROUND.

746. The U. S. Naval Proving Ground is situated at Indian Head, Md., and comprises a tract of land of nearly 2200 acres on the left bank of the Potomac River, about 25 miles below Washington. There is a clear range over the water of 17,000 yards.

This is commonly known as the Upper Station. The Lower Station at Dahlgren, Va., is 45 miles below Indian Head on the right bank of the river. Its area is about 1300 acres and its water range extends over 100,000 yards to Tangier Shoal in Chesapeake Bay. By 1923 nearly all proof work will probably be done at Dahlgren.

747. The new proving ground at Dahlgren is laid out in four batteries with parallel lines of fire down the river, as follows:

Broadside	8″ to 1-pdr.	guns.
Main	10″ to 18″	"
Butts	12″ to 18″	"
Fuse and Thin Plate Butts......	8″ to 1-pdr.	"

748. In addition to batteries certain essential housing units are required for equipment:

Physical laboratory, containing instruments, plotting room, etc.
Bombproofs, providing shelter for ammunition and personnel.
Shell house, for measurement and preparation of shell.
Filling houses, for filling shells with high explosive.
Bag house, for manufacture of bags.
Quilting house, for sewing in ignitions.
Assembly house, for assembling fixed ammunition.
Magazines, for stowage of stock ammunition.
Explosion chambers, for fragmentation work.
Explosive sheds, for preparation of mines, etc.

749. All guns, gun carriages, ammunition, armor and new devices in naval ordnance are tested at the Proving Ground before being accepted for service.

750. The Ordnance Department at the Proving Ground is divided into: Gun, powder, butt, ranging, aviation and experimental divisions.

751. Proof of guns and mounts.—Every gun manufactured for the naval service is submitted to proof before being sent aboard ship.

752. Guns are built at private plants or at the Naval Gun Factory. After preliminary examination by government inspectors, guns are shipped to Proof Shop in Washington Navy Yard, where lapping out, bore searching and star gauging are done. Thence gun is shipped to Proving Ground.

753. Proof consists of five rounds:

1. Low, from 7 to 12 tons.
2. Service, around 16 tons for modern 45- and 50-caliber guns.
3. Near proof, about one ton less than proof.
4. Proof, 25 per cent overload, not exceed 20 tons.
5. Service.

754. Lined guns are given an extra proof round.

Desired pressures are obtained by using powders of well-known regularity kept on hand for station use. Accurate curves of such powders are always available. To secure proof pressure a faster powder (*i. e.,* higher pressure for same weight of charge) is frequently necessary, due to high density of loading.

755. Accuracy, precision and scrupulous care are vital to good proof work. Laboratory methods are not lacking: every test is experimental in the sense that results from use of any new piece of ordnance are always uncertain. Thus, before proving a gun

Bore is carefully examined.

Chamber, rifling, and built-up parts are studied for defects.

Breech mechanism is worked slowly.

Ammunition is prepared with equal care:

Temperature of powder taken.

Weight of charge and ignition carefully checked.

Shell and band dimensions taken with micrometer.

Shell weighed.

Shell seating measured.

All data is entered on a large form sheet called the "firing record." This is copied into smooth books, which constitute a running log of all firing at the Proving Ground.

Next, pressure gauges (see paragraph 802) are got ready and put in gun behind charge. Abnormal readings are thrown out. As this method is probably not accurate closer than one-half ton,

three gauges are always used and six for proof rounds in major-caliber guns.

756. After firing each round a thorough inspection is made of gun and mount for

Damage to lands.
Shifting of tube or hoops.
Cracks in screw box, plug, or muzzle.
Recoil and counter-recoil.
Blowbacks and obturation.
Primer vent.
Salvo latch.
Elevating and training gear.
Damage or failure in any way of mount.

757. Common defects in guns are invisible without bore searching the gun. Occasionally a pressure gauge is shot out giving a characteristic series of deep bruises oppositely distributed along the bore. A steel splinter or fragment may tear or roll up an entire land. When shells break up the damage appears to combine that caused by gauge and splinter. To avoid such injuries shells are always wiped clean and examined before firing.

758. Some guns are given special proof as follows:

12"/45 guns and above are given two 20-ton rounds.

Relined guns are given an extra round below service pressure to set the liner. Essential difference between new and relined guns lies in the fact that repeated firing in service has set up stresses and states of crystallization in the old gun that prevent the same pressure of fit obtainable in shrinking the jacket and tube (or liner) together in a new gun.

All semi-automatic guns are given ten extra service rounds of rapid fire to test breech mechanism.

Type guns, *i. e.*, guns of new design, are given a more thorough series of tests, velocities always taken, and shells ranged.

759. After proof the gun is returned to the Naval Gun Factory at Washington, where it is stamped with the letter "P," and the initials of the officer in charge at the Proving Ground. It is thoroughly inspected and star gauged before issue to service.

760. Target, common, obsolete A. P. shell, or slugs, are used in proof of gun. Provided pressures can be obtained and the shell's band fits the gun, economy is the deciding factor in the choice of proof projectiles.

761. **Mounts** are generally proved at time gun is being proved. In case mount alone is being proved, only three rounds are fired: Service, proof (one ton below proof pressure for that type of gun), and service.

762. Some mounts are given special proof:

4″ twin-mount guns are fired in salvo for the last round and elevated 20°.

3″/50 Mark VII Mod. 2 (high angle) mount has last round fired at 30°.

Turret mounts are not proved except in case of new design.

25 per cent of all deck lugs for new ships are proved by being fitted in station girders during proof of guns.

Type mounts are given extra rounds in proportion to the degree of change made from standard mounts.

Slides are proved with new guns. No special rounds are fired unless examination of recoil record shows slide's performance is unsatisfactory. Major-caliber guns are fitted with Tabor indicators.

763. **Proof of powder.**—An "index" of powder is, generally speaking, the largest amount of a single kind of powder that the capacity of the manufacturing plant is capable of blending. Blending houses are usually large enough to mix 125,000 pounds, and this number therefore represents the maximum weight of one index. The weights of the indices of the various sizes of powder are given in the Bureau of Ordnance Specifications for the Manufacture of Powder.

After the manufacturer's lot is boxed and ready for shipment, a sample of the prescribed weight is sent to the Proving Ground for proof:

764. On the battery the following program is carried out:

(a) Powder sample is heated for at least three days in constant temperature magazine until it has acquired a uniform temperature of 90° F. (32° C.).

(b) Curve of some powder with similar characteristics is laid out for reference.

(c) A warming round is fired.

(d) A small charge of the new powder, estimated to give about 2000 f. s., is carefully weighed, stacked (if 12″ or above) and fired.

(e) By plotting this point on the velocity-charge sheet and applying the "Le Duc slope" successive rounds are selected, weighed, stacked and fired. (The Le Duc slope is obtained from the Le Duc formulas, which are mathematical expressions of the relations between gun, powder and velocity, using as arguments the known dimensions of each). (See paragraph 113 and Plate V, Chapter III.)

(f) A new curve is fixed through the series of shots. Service, reduced and target practice charges are assigned from the points at which the curve cuts velocity and charge for these.

(g) A pressure curve is plotted at the same time.

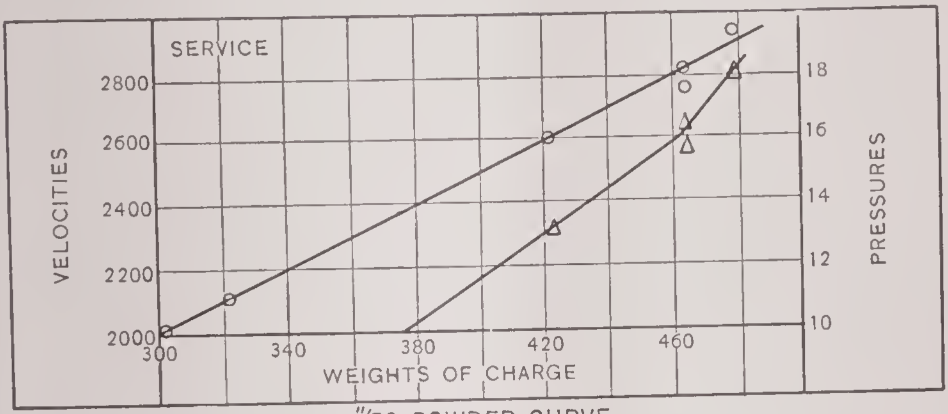


FIG. 125.

A powder may be rejected for an irregularity of one-half of 1 per cent of service velocity; thus an average of 14 f. s. error is allowed for a 2800 f. s. powder. Failed powder may be redried or reblended for further test.

765. Pressures must be of fair regularity, and the pressure curve not too steep.

Assigned charges and pressures must also be within limits set by specifications.

A powder's web-thickness, volatiles, and nitration determine its fitness for use in any particular gun.

During the firing of the proof powders, a sample is taken out and sent to the laboratory for analysis, in order to ascertain whether the stability, percentage of nitrogen, residual volatiles and solubility are in accordance with the specifications.

766. Powder for current use is blended from time to time and stored in the proving-ground magazines.

Guns of all calibers and all known indices of powder are kept on the station at all times for use in the proof work.

767. After fixing the charge, a report of the ballistic and chemical qualities is forwarded to the Bureau of Ordnance, upon which the powder is either accepted or rejected. If accepted, an index number is assigned and, together with the charge and manufacturer's lot number, is stenciled on the boxes, and the index is shipped to a magazine.

768. **Proof of shell.**—The navy purchases: "Armor-piercing shell," target shell, common shell, proof shot ("slugs"), high-capacity shell, illuminating shell, marker shell, and shrapnel.

Armor-piercing shell are manufactured in lots of 500. None below 6 inches are now made. Inspection and metallurgical tests are made at the projectile plant. Four projectiles are selected from each lot, banded and capped and shipped to the Proving Ground for ballistic test against armor. In addition four projectiles will be selected from the first lot of each caliber, capped and banded, three to be fired for flight and one to be burst for fragmentation. These projectiles must give smooth flight; must not break up, upset or strip their bands, or develop faults which would seriously affect their value as projectiles. The dispersion and ranges of the projectiles fired for flight under favorable conditions shall not differ greatly at any range from those of standard projectiles already in the service; and, in all, the dispersion shall be such as not to affect their value as service projectiles. Should the ballistic test indicate that these projectiles have developed any fault which will seriously affect their value as projectiles, the bureau reserves the right to be furnished with three additional test projectiles from the lot in order to determine the fault in question.

769. The ballistic test against armor requires that two out of four projectiles pass through face-hardened plate and be recovered in effective bursting condition. This effective condition is judged by whether or not the cavity is exposed. Angle of plate to line of fire and velocity of shell are set forth in current Bureau of Ordnance specifications. Latitude of 40 foot-seconds in striking velocity is allowed the Proving Ground. Plate is selected so as to have its thickness equal to that of the shell's diameter. In the case of 16-inch shell such plate is not always available. Velocity is then altered in accordance with the De Marre formula.

A retest of a rejected lot may be permitted, in which three shells out of four must pass.

770. Charges for shell test are picked from curves of powder in current use. Corrections for temperature (about 2 foot-seconds for each degree F.) and for erosion are made.

A pasteboard screen is placed in the line of fire in forward velocity screen to ascertain if the shell flights truly, *i. e.*, with its axis tangent to line of fire, or to show if it breaks up.

After impact the dimensions and position of impact are noted. The shell is recovered, inspected, and photographed. Occasionally heat cracks develop in the shell while it lies in the sand pile it has entered after leaving plate. These defects are not ordinarily held against the shell.

771. *Common shell* include all calibers below 7 inches, and they are now fired at homogeneous plates of a thickness equal to about one-third the caliber of the shell. The projectile must pass through the plate unbroken and be recovered in a condition for effective bursting. At present one per lot is tested against plate.

Common shell are also fragmented and fired down the range according to the specifications. A shell is loaded, fused, and exploded in an explosion chamber. To be satisfactory, all parts must break up well. The shells fired down the range must not break up, upset, or strip their bands; and the dispersion must not be greater than that given by standard shell. All common shell tested on plate or on range will be brought to exact weight by blind loading.

772. *Target shell* and *proof shot* are fired for flight only. Both are of cast iron and are used for economy. The former are identical in design with A. P. shell; the latter are similar in weight, while cylindrical in shape. Three target shells of a lot are fired down the range in comparison with two or more of an accepted lot; they must give smooth flight and not strip their bands nor show erratic dispersion.

773. *Ranging* is always done under the most uniform conditions.

774. Special attention is paid to accurate shell and band measurements, shell seating, weight of charge, position of center of gravity, eccentricity of shell form. Shells having special wind shields require an extra scrutiny just before nose enters gun; these shields occasionally knock loose.

775. The line of fire is established with a theodolite. Gun is trained and set at elevations up to about 18°, using clinometer, or gunner's quadrant. Elevation of gun depends on purpose of ranging. If for coefficient of form or routine test of shell a single elevation of about 8° is sufficient. For checking range tables or investigating new type of shell various angles are necessary up to limit of screen lines.

776. Observers with theodolites or transits are stationed at various points down the range to get horizontal angles of fall of shots. They are stationed so a good "cut" can be obtained. Observations are plotted on a special table in the physical laboratory on which range stations are laid down to scale. Cameras and rakes may also be used for work involving simultaneous splashes.

777. From data obtained in ranging a shell its coefficient of form is computed, which information is necessary in working out the "range tables." Later, as opportunity arises, various computed ranges of the table are checked.

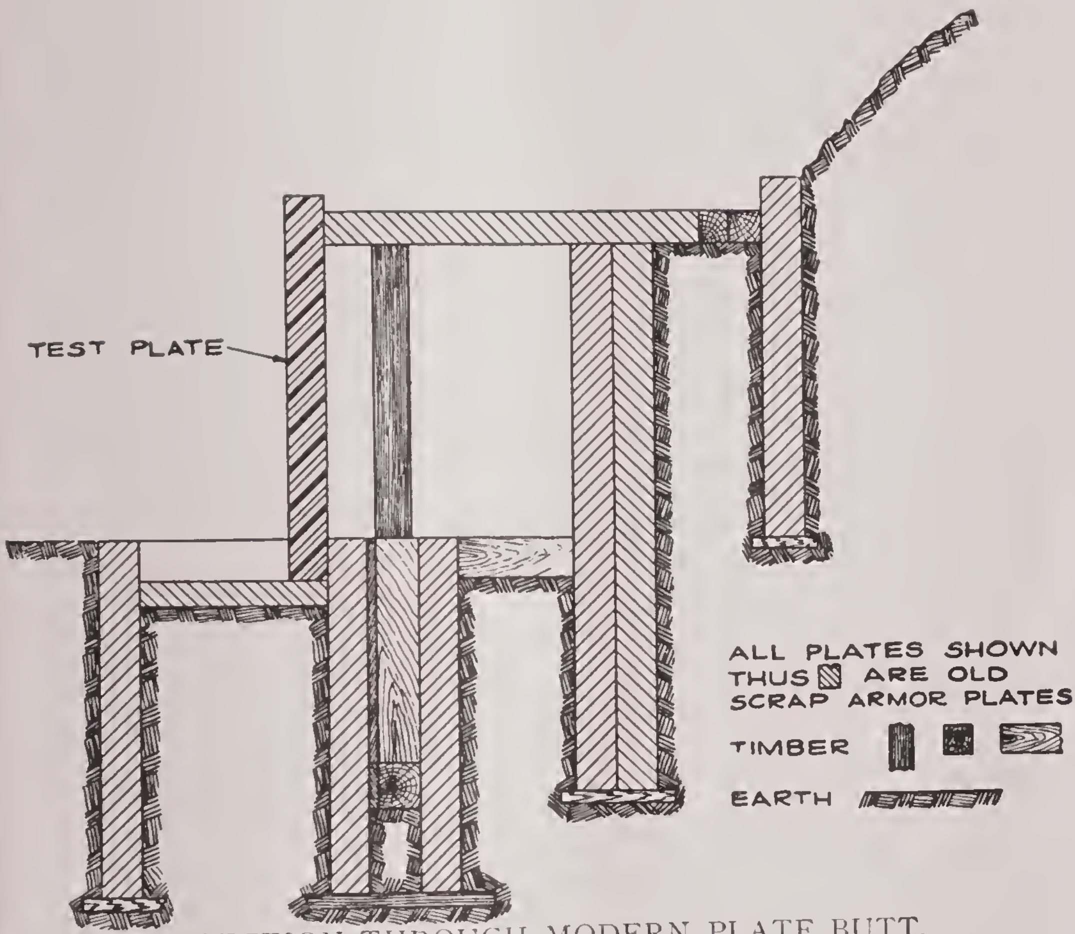
778. Meteorological conditions at time of firing are carefully recorded. Long-range firing is accompanied when practicable by exploration of the upper air strata, using aeroplanes and sounding balloons. The sounding balloon carries a combined barograph and thermograph. Angular observations from the earth's surface give a fair plot of anemometric data.

779. *High-capacity shell* are ranged in groups of three for each lot in comparison with one or more individuals of an accepted lot. Usually several shell from a contract are fired loaded and fused.

780. *Shrapnel* are given flight and fragmentation test and ranged. New types are fired in a covered butt which permits recovery.

781. *Star shell* are ranged and flighted for test of illuminating element. Other pyrotechnic projectiles, such as marker shell, spotting shell, etc., are ranged for coefficient of form, strength and stability in flight, and efficiency of element contained.

782. Proof of armor.—Armor is proved ballistically under specifications by the Bureau of Ordnance. These specifications are periodically rewritten in order not only to keep up with the development of naval ordnance, but to insure that quality of production be held to highest standard possible.



SECTION THROUGH MODERN PLATE BUTT.

For ballistic purposes armor is divided into Class A, or face-hardened armor, and Class B, or rolled or forged steel plates.

Generally speaking, Class A armor is attacked normally with even-caliber shell.

Class B armor above 5 inches is tested with calibers about twice its thickness; below 5 inches, 12-inch to 6-inch guns are used. Angle of attack varies from 9° to 33° from line of fire.

Butts are ponderous structures of old armor plates and concrete with a sand hill behind to catch and hold the shell. Heavy oak timbers are wedged in as spacers between butt proper and ballistic plate. The problem of holding an armor plate buffeted by thousands of foot-tons of energy has only been solved very recently. Plate II shows an armor plate mounted in a butt ready for test. Even yet the methods are crude and cumbersome.

Shell and charge are selected as for shell test with reference to velocity required. Class A plate is given two rounds and, to be successful, must prevent base of either shell from passing completely through. Through cracks to edge of plate or to another impact also fails the plate. Centers of impacts must not be closer together than $2\frac{1}{2}$ calibers of shell used, or to edge of plate. (See Chapter XIV, Plate VI.)

Class B plate must resist one impact of specified energy; and, to be successful, must not be pierced nor develop through cracks.

Best modern shell are used in tests of armor. Also the inspector of ordnance at the steel works selects a plate from each group which, in his opinion, will give the poorest results.

Cardboards and screens are used as in other firing.

783. **Proof of fuses and tracers.**—A contract for fuses always specifies what ballistic test the finished article must stand.

Tracer detonator fuses, major, medium and **minor caliber ignition fuses** are given the following tests:

(a) Drop test: Fuses are fitted in shell and dropped 30-40 feet point or side down on a 4-inch iron plate. Plunger must not arm or mark the primer cap.

(b) Fragmentation test: Fuse must satisfactorily fragment a loaded shell or shells. This is done in closed chamber or against plate in covered butt.

(c) Flight test: Fuses are fired in loaded shells over the range to test action of fuse plunger under retardation. Projectile must not burst or fuse blow out during flight.

(d) Plate test: A prescribed number of each lot of fuses are fired in loaded shell against thin plate (3/16″ to 4½″, depending on type of fuse. A given percentage must provide high-order detonations some distance behind plate.

Various other fuses, such as time fuses, marker shell fuses, anti-submarine detonating fuses, long delay action fuses, etc., are given practically the same tests as above, depending on nature of fuse. Plate tests are, of course, omitted for time fuses and others not supposed to function through armor.

784. Proof of primers.—All primers are now manufactured by the Washington Navy Yard and Torpedo Station, and are proved under instructions issued from time to time by the Bureau of Ordnance.

Chronoscope times are taken to check new design of primer, or when test is especially ordered.

Primers are usually made in lots of one thousand, and five of each lot are sent to proof. As far as practicable primers are proved during current work.

785. Bag gun combination primers are tested by firing one or two of a lot by percussion, the rest electrically, at service pressures or above. Unless the fault is clearly traceable to a cause outside the primer, all must fire on first attempt. Usual faults are:

Cracking of insulation.

Imperfect obturation.

Cracks in stock.

Burning or fusing of stock.

Sticking in seat.

Stripping of threads.

In all cases, rejection depends upon degree of imperfection.

786. Mark XIII (screw combination extension magazine) primers are tested by firing one or two of a lot electrically, the rest by percussion. As least two should be fired at or above service pressure. Mark XIV (screw percussion extension magazine) primers are usually fired at or above service pressure.

Unless the cause is clearly traceable to some cause outside the primer, all must fire on first attempt. Usual faults are same as with bag gun combination primers.

787. When a primer misfires in percussion firing no second attempt should be made, but primer removed and returned to

manufacturer. A primer being tested and failing electrically should not be fired by percussion as this may destroy any clue to its electric failure.

In case of failure the primers are returned with the report to the Bureau of Ordnance. These reports include the approximate pressure, caliber of gun fired in, functioning of primers, and any damage to the primers or stocks.

788. Proof of cases.—As far as practicable cases are proved during current work. Various numbers constitute a "lot" of cases, from 100 for 6"/40 to 1000 for 3"/50 and smaller. From one to four cases from each lot are sent for proof.

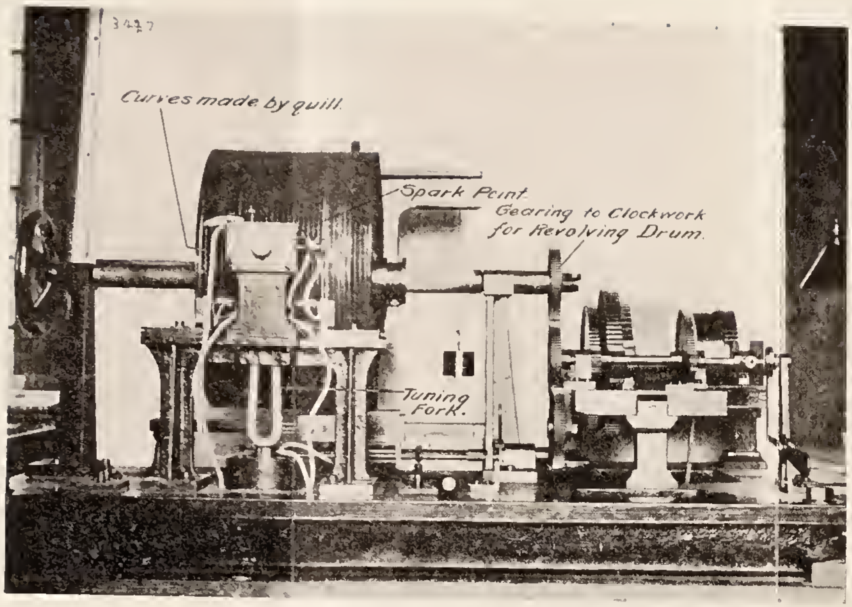
Each proof case must fire three rounds at or above service pressure, unless it fails on the first or second round. To pass satisfactory test, a case must be free from cracks or serious fluting; must permit the primer to be withdrawn with reasonable ease, and, after three rounds, must reload easily in the gun in which it was fired, and eject easily therefrom.

If a case is otherwise satisfactory, expansion at the mouth after firing, so that the projectile is no longer a tight fit, is not considered cause for rejection.

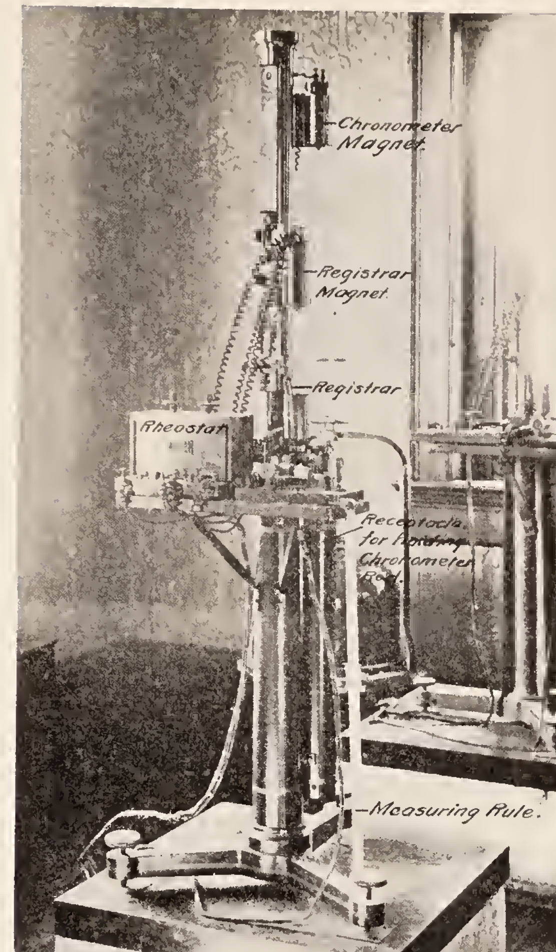
789. Proof of explosives, etc.—Tests of explosive "D," TNT, rockets, bombs, mines, grenades, depth charges, etc., are continually going on at the Proving Ground. A general policy of specious thoroughness bulwarks the special schedule laid down by the Bureau of Ordnance for each particular kind of proof. With a large chemical laboratory on the station and the gun factory shops so close at hand broad facilities are available for every branch of ordnance investigation.

790. Experimental proof work.—One division of the proof department spends its entire time in pursuit of information on existing problems, and in the development of new and better types. Closely allied are the experimental ammunition unit, which specializes in the preparation of ammunition, and the Special Board of Ordnance in the Navy Department, which directs its Proving Ground research through the experimental desk in the Bureau of Ordnance.

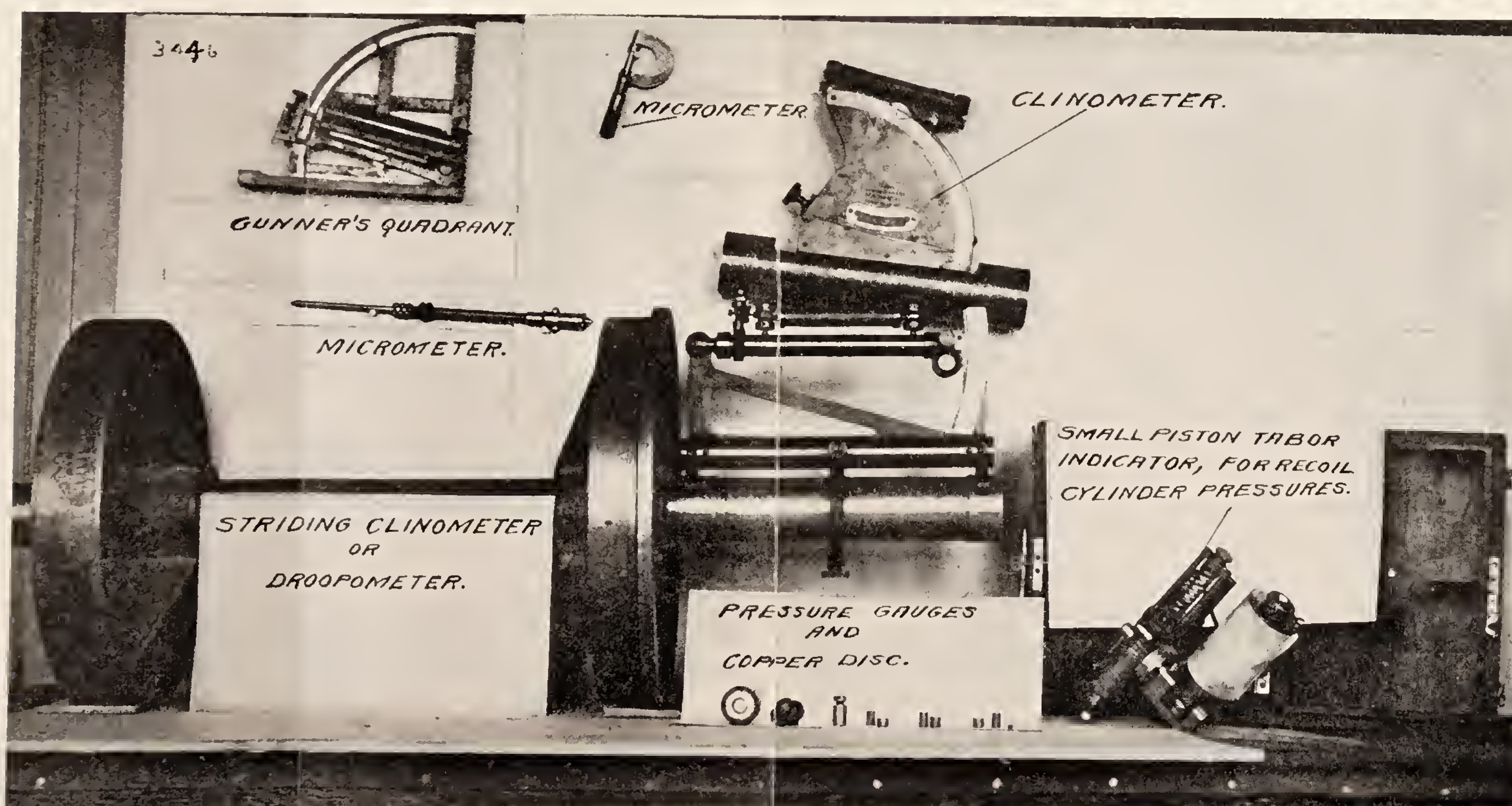
Under the experimental division come meteorological and sondage work. Also most aeronautic ordnance and uses of airplane in spotting and bombing are still largely in an experimental stage, so far as their connection with proof work is concerned.



SCHULTZ CHRONOSCOPE.



CHRONOGRAPH.



INSTRUMENTS USED IN ORDNANCE WORK.

791. *Erosion* is one of the special problems which require years for solution. By comparing the velocity and pressure losses in station guns at various points in their lives with new guns of similar calibers erosion curves are plotted; dispersion, types of rifling bands, shell forms, are other such problems.

Measurement of Velocity and Pressures.

MEASUREMENT OF VELOCITY.

792. In measuring the velocity of a projectile, the time of passage of the projectile between two points, a known distance apart, is recorded by means of a suitable instrument. The calculated velocity is the mean velocity between the two points and is considered as the velocity midway between the points. In order that this may be done without material error, the two points must be selected at such a distance apart in the path of the projectile that the motion of the projectile between the points may be considered as uniformly varying and the path a right line.

793. **Le Boulengé chronograph** (Plate III).—The instrument generally employed for measuring the time interval in the determination of the velocity was invented by Capt. Le Boulengé, of the Belgian Artillery, and is called the Le Boulengé chronograph. It has been modified and improved by Capt. Breger, of the French Artillery. This instrument (see Fig. 126), consisting, essentially, of a brass column *a*, supporting two electromagnets *b* and *c*, is mounted on the triangular bedplate *d*, which is provided with levels and leveling screws. The magnet *b* supports the long rod *e*, called the "chronometer," which is enveloped when in use by a silvered-zinc or copper tube *f*, called the "recorder." A nut above the recorder holds the recorder fixed in place on the chronometer rod. The magnet *c*, which supports the short rod *g*, called the "registrar," is mounted on a frame which permits it to move vertically along the standard. Fastened to the base of the standard is the flat spring *h*, which carries at the outer end the square knife *i*. The knife is held retracted or cocked by the trigger *j*, which is acted upon by the spring *k*. The chronometer *e* hangs so that one element of the recorder is close to the knife. The registrar *g* hangs immediately over the trigger. When the electric circuit through the registrar magnet is broken, the registrar falls on the trigger and releases the knife, which flies

out under the action of the spring h and nicks or indents the recorder. The tube e receives the registrar as it falls. Adjustable guides are provided to limit the swing of the two rods when first

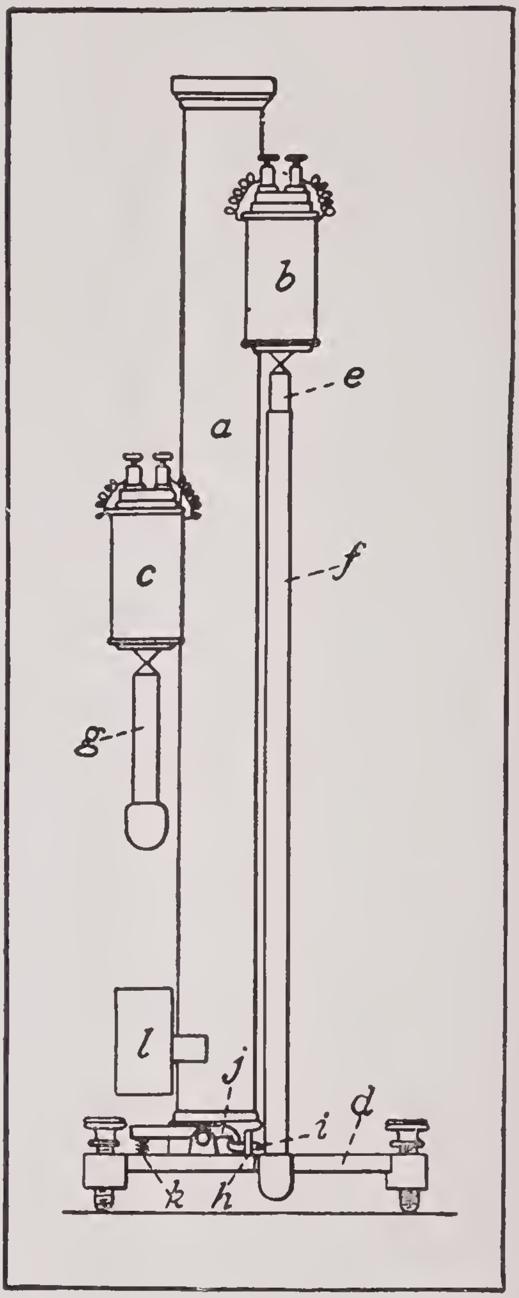


FIG. 126.

suspended. The stand or table on which the instrument is mounted is provided with a pocket which receives the chronometer when it falls at the breaking of the circuit that controls its magnet.

A quantity of beans in the bottom of the pocket arrests the fall of the chronometer without shock.

The chronometer circuit is led through a contact piece (not shown) carried by the spring *h* and so arranged that the chronometer circuit cannot be closed until the knife is cocked. This arrangement prevents the loss of record through failure to cock the knife when suspending the rods before the piece is fired.

In the use of the chronograph in measuring the velocity of a shot the following accessory apparatus is required: Targets, measuring rule, rheostats, and disjunctor.

794. Targets.—Two wire targets, usually spoken of as "screens," each made of continuous wire (Fig. 127), are erected

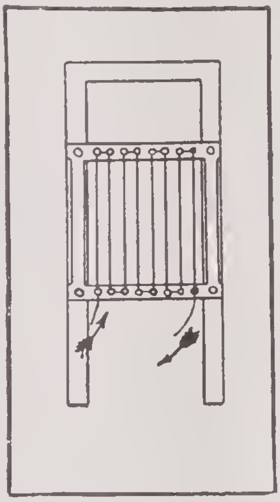


FIG. 127.

in the path of the projectile. The targets form parts of electric circuits which include the electromagnets of the chronograph. Each magnet has its own target and its own circuit independent of the other. The circuit from the nearer or first target includes the chronometer magnet.

The circuit from the second target includes the registrar magnet. On passage of the projectile through the first target the circuit is broken, the chronometer magnet demagnetized, and the long rod, or chronometer, falls. When the projectile breaks the circuit through the second target, the short rod or registrar falls and, striking the trigger, releases the knife, which, flying out, nicks the recorder at the point which has been brought opposite the knife by the fall of the chronometer.

The first target must always be erected at such a distance from the gun that it will not be affected by the blast. For small arms it is placed 3 feet from the muzzle and consists of fine copper wire wound backwards and forwards over pins very close together. For cannon it is placed from 50 to 250 feet from the muzzle, depending upon the size of the gun. For the measurement of ordinary velocities the targets are usually placed 100 feet apart for small arms and 163 feet, or 50 meters, as is the practice at our proving grounds, for cannon.

To avoid the effect of the blast from large guns, the first target should be placed about one-tenth of the expected velocity, in feet, from the muzzle. For example, when firing the 14-inch gun at a velocity of 2600 foot-seconds, the first target should be about 250 feet from the muzzle.

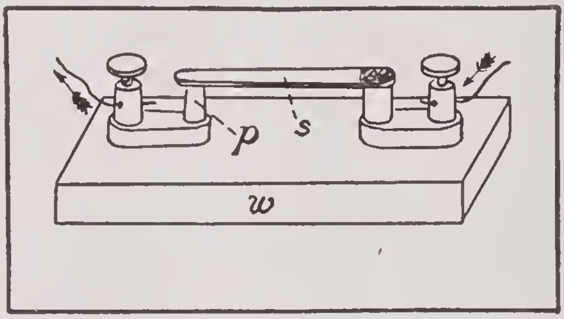


FIG. 128.

The second target for small arms consists of a steel plate to stop the bullets, having mounted on its rear face, and insulated from it by the block *w* (Fig. 128), a contact spring *s*, contact pin *p*, and their binding screws. When the bullet strikes the plate the shock causes the end of the spring to leave the pin and thus breaks the circuit, which is immediately re-established by the action of the spring. By means of this device constant repairing of the target is avoided.

795. **Measuring rule.**—For measuring the height of the mark on recorder above the zero mark there is provided with the instrument a rule graduated in millimeters, and with a sliding index and vernier, the least reading being one-tenth of a millimeter. The swiveled pin at the end of the rule (Fig. 129) is inserted in the hole through the bob of the chronometer, and the knife-edge of the index is placed at the lower edge of the mark whose height

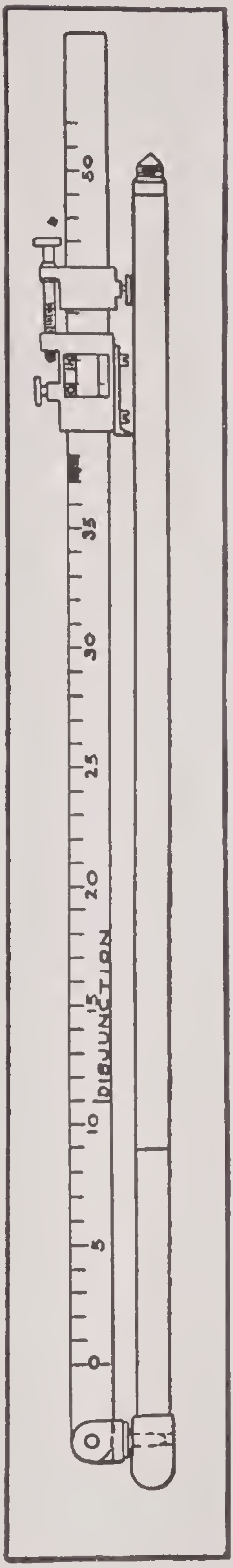


FIG. 129.

is to be measured. The height is then read from the scale. Tables are constructed from which can be directly read the time corresponding to any height in millimeters within the limits of the scale. The maximum time that can be measured with this chronograph is limited by the length of the chronometer rod and is about 0.15 of a second.

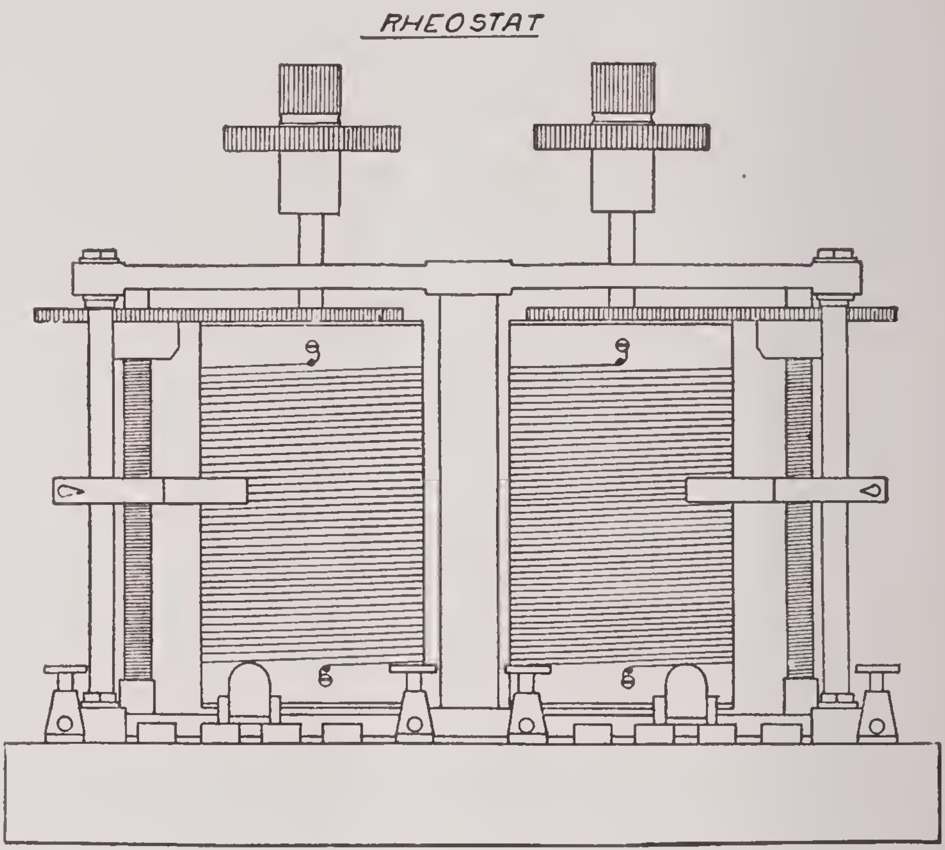


FIG. 130.

796. The rheostat.—Both circuits are led independently through rheostats, by means of which the resistance in the circuits may be regulated and the strength of the currents through the two magnets equalized.

One form of rheostat is shown in Fig. 130. The current passes through the contact spring *a*, and through a German silver wire wound in grooves on the wooden drum *b*.

By turning the thumb nut, *c*, the contact spring is shifted, and more or less of the wire is included in the circuit.

Another form of rheostat, through which both circuits pass independently, is shown in Fig. 131, and this is the form used in our service. Each current passes through a strip of graphite, *a*, and the resistance in the circuit may be increased or diminished by sliding the contact piece, *b*, so as to include a greater or less length of the graphite strip in the circuit.

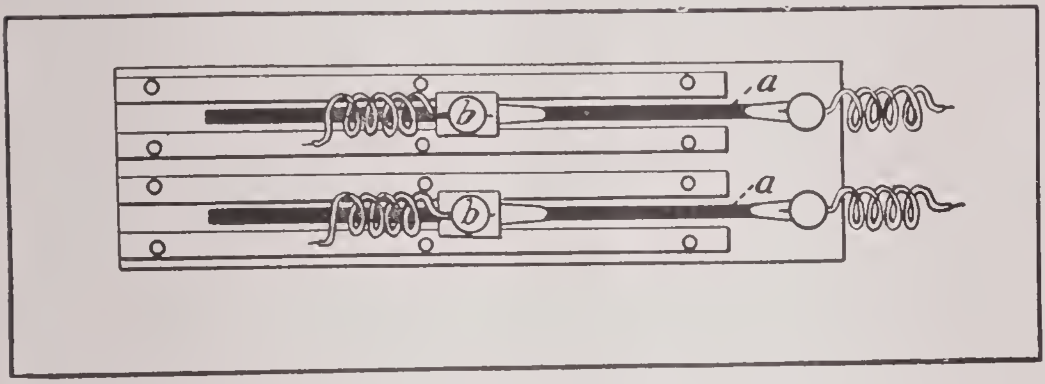


FIG. 131.

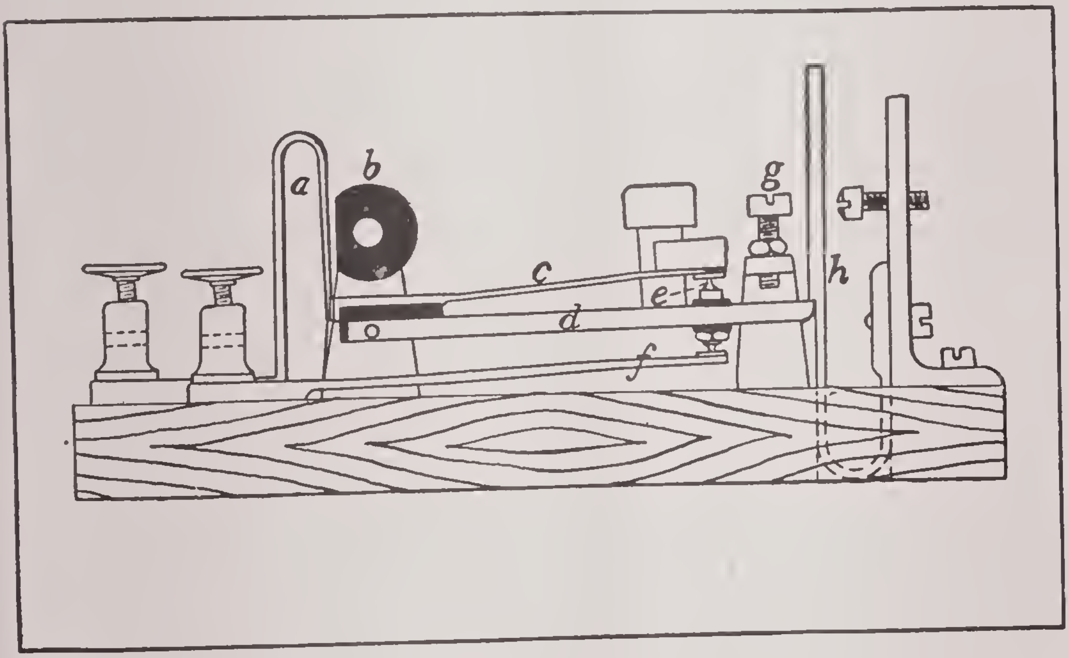


FIG. 132.

797. The disjunctor.—Both the circuits also pass independently through an instrument called the "disjunctor," by which they may be broken simultaneously. The disjunctor is shown in elevation and part section in Fig. 132. The two halves of the instrument are exactly similar.

The two contact springs, *c,* weighted at their free ends, bear against insulated contact pins, *e,* supported in the same metal frame, *d.* The frame is pressed upwards against the spring catch, *h,* by two other contact springs, *f.* The electric circuit passes from one binding post through the parts *f, e, c,* and *a* to the other binding post.

On the release of the spring catch, *h,* the frame, *d,* flies upward under the action of the springs, *f,* until stopped by the pin, *g.* At the sudden stoppage of the movement the weighted ends of the contact springs simultaneously leave the contact pins, thus breaking both circuits momentarily. Mounted on a shaft are two hard-rubber cams, *b,* which bear against other springs, *a,* in the two circuits. On turning the cam shaft the connection between the parts *a* and *c* is broken, breaking both electric circuits, but not necessarily simultaneously. The circuits are habitually broken in this manner except when taking disjunction or records in firing.

By means of the disjunctor both circuits are broken at the same instant. The mark made by the knife under these circumstances is called the disjunction mark, forming the datum point for the instrument. This point includes any difference in the times required for demagnetization of the two magnets, the time occupied by the registrar in falling, and the time required for the knife to act.

From the height of the disjunction mark as measured we obtain the corresponding time from the law of falling bodies:

$$t=\left(\frac{2h}{g}\right)^{\frac{1}{2}}$$

Now, when the circuits are broken by the projectile, the chronometer begins to fall before the registrar. The mark made by the knife will therefore be found above the disjunction mark. If we measure the height of this second mark above the zero, the corresponding time is the whole time that the chronometer was falling before the mark was made, and to obtain the time between the breaking of the circuit we must subtract from this time the time used by the instrument in making a record or the time corresponding to the disjunction. Let h_1 and h_2 represent the heights of the disjunction and record marks, respectively, t_1 and t_2 the corresponding times. Let t be the time between the breaking of the screens; then,

$$t=t_2-t_1=(2h_2/g)^{\frac{1}{2}}-(2h_1/g)^{\frac{1}{2}}.$$

It will be seen by the equation that *the difference of times, and not the difference of heights,* must be taken.

798. Fixed disjunction.—For the velocity at the middle point between targets we have, representing by s the distance between the targets,

$$v=s/t.$$

Substituting for t its value, we have

$$v=\frac{s}{(2h_2/g)^{\frac{1}{2}}-(2h_1/g)^{\frac{1}{2}}}.$$

From this equation we see that if the value of s and of $(2h_1/g)^{\frac{1}{2}}$, the disjunction, be fixed, the values of v can be calculated for all values of h_2 within the limits of practice and tabulated. This has been done for the values: $s=100$ feet and $(2h_1/g)^{\frac{1}{2}}=0.15$ seconds. This value of $(2h_1/g)^{\frac{1}{2}}$ is called the *fixed disjunction.* If such a table is not at hand, the fixed value of the disjunction avoids the labor of calculating $(2h_1/g)^{\frac{1}{2}}$ for each shot, as in this case we have

$$t=t_2-0.15 \text{ sec.}=(2h_2/g)^{\frac{1}{2}}-0.15.$$

In ordinary practice it is better to take the disjunction at each shot and to keep the disjunction mark near the disjunction circle, but not necessarily on it. The times corresponding to the heights of the disjunction and record marks are both read from the table, and with the difference of these times the velocity is taken from another table.

The velocity obtained is that at a point midway between the two screens. A correction, found by the methods of exterior ballistics, is applied to reduce this to the muzzle of the gun whence it becomes the *initial velocity*. For practical use curves are computed from which the correction is picked off.

The velocity obtained is, of course, that half way between the screens, and to obtain the actual muzzle velocity of the gun, this must be reduced to the muzzle by exterior ballistic formulas. (See Art. 108, Alger's Exterior Ballistics, 1915.)

$$C=\frac{w}{d^2};\ S=C(S_{v_2}-S_{v_1});\ \text{whence } S_{v_1}=S_{v_2}-\frac{S}{C}.$$

Where V_2=velocity midway between the screens, V_1=initial velocity, S=distance from the muzzle to point half way between the screens, d=diameter of shell, w=weight of shell, C=ballistic

coefficient uncorrected for atmospheric conditions, and S_{v_2} and S_{v_1} are found in Table I of the Ballistic Tables, 1914.

At the Proving Grounds curves have been calculated from which we pick off for each caliber the quantity to add to the measured velocity to give the initial velocity.

Example.—In the Naval Academy pistol gallery there are screens 67 feet apart, the first being 6 feet from the muzzle. The measured velocity being 772 feet, find the initial velocity. In this case $V_2=772$, $S=39.5$, $C=.18865$ (given in description of the pistol).

S 39.5 ....log 1.59660
C .18865 log........9.27566.........colog 0.72434
log 2.32094.. 209.38
16248.40

$S_{v_1}=16039.02$
$V_1=\ \ 779.6$

799. **Adjustments and use of the chronograph.**—The instrument must be properly mounted on a stand at such a distance from the gun that it will not be affected by shock of discharge. The electrical connections with the batteries and targets, through the rheostats, *r*, and disjunctor, *d*, are made as shown in Fig. 133.

To adjust the instrument, first level it by the leveling screws, cock the knife, and suspend the chronometer rod enveloped by the recorder from its magnet. See that the recorder hangs close to the knife and that no part of the base of the rod touches any part of the instrument. The guides must be close to, but not touching the bob of the chronometer. Release the trigger, and the knife will then mark the recorder near the bottom. This mark is the zero from which all heights are measured, and the knife-edge on the measuring-rule index must be so adjusted that the zero of the vernier shall coincide with the zero of the scale when the knife-edge is in the mark. The adjustment of the knife is made as follows: Place the sliding index so that the zero of the vernier is at the zero of the scale on the rule. Clamp the index and apply the rule to the chronometer. Loosen the screws that hold the knife and adjust the knife-edge to turn the recorder around the chronometer rod. The knife-edge will scribe a circle on the recorder, and the mark made at the disjunction should fall on or near this circle.

To regulate the strength of the magnets each of the rods is provided with a tubular weight, one-tenth that of the rod. Place the proper weight on each rod and suspend the rods from their magnets. Increase the resistance in each circuit by slowly moving the contact piece of the rheostat until the rod falls. Remove the weights from the rods and again suspend the rods. Take the disjunction. If the bottom of the mark made by the knife does not lie on or near the circle previously scribed on the recorder, raise or lower the registrar magnet until coincidence is nearly obtained.

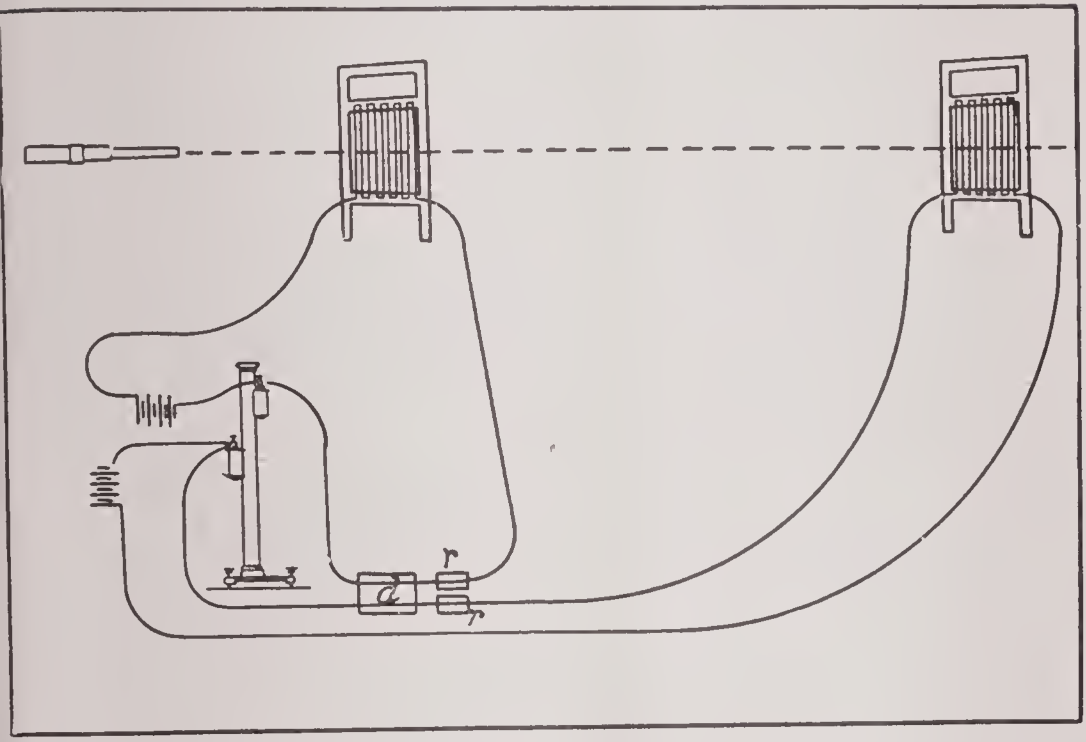


FIG. 133.

Test the disjunctor by shifting the two circuits. The height of disjunction should remain the same. Test the circuits by suspending the rods and causing the circuits to be broken successively at the two targets. Note that the proper rod falls as each circuit is broken.

Always suspend the chronometer rod with the same side of the bob to the front—to do this it is usual to have the number on the bob toward you—and always, before suspending it, press the recorder down hard against the bob. After each record turn the recorder slightly on the rod to present a new element to the knife.

Circuits should always be broken at the disjunctor when the rods are not actually suspended, and the rods should be allowed to remain suspended as short a time as possible.

800. Measurement of very small intervals of time.—For the measurement of very small time intervals the registrar magnet is raised to near the standard and placed in the circuit with the first target. The chronometer magnet is put in the circuit with the second target. Under this arrangement the disjunction mark will be made near the top of the recorder and the record mark under the disjunction. The interval of time is obtained by subtracting the time corresponding to the height of the record mark from the time of disjunction. The object of this arrangement is to obtain the record when the chronometer has acquired a considerable velocity of fall, so that the scale of time will be extended, and small errors of reading will not produce large errors in time.

For velocity work at the Naval Proving Ground three Le Boulengé chronographs are used. A separate circuit and screens are provided for each instrument. These triple screens are placed a few inches apart, the first of one set being exactly 50 meters from the first of the second set. The use of these three chronographs permits the selection of the most probable results in case the results vary. The results seldom differ, however.

801. Schultz chronoscope (see Plate III and Fig. 134).—The Le Boulenge chronograph measures a single time interval only. Where more exact results must be obtained in time measurements, such as velocities of recoil and counter-recoil, the firing interval, or in any case where several *consecutive* intervals must be measured, an instrument called the Schultz chronoscope is used.

This instrument consists, essentially, of a nickel-plated cylinder, *a*, revolving by means of a falling weight, the speed of rotation being rendered constant by means of a fan in gear with the mechanism. A stylus, *h*, is fastened to one prong of an electrically sustained tuning fork, *b*. The breaking of an electric circuit is the means employed to mark successive intervals of the measurement; the break causing a spark to leap across from a point near the stylus on the tuning fork to the metal cylinder, the latter having been coated lightly with lampblack just before the measurement is to be made. As the cylinder revolves and the tuning fork vibrates

a wavy line is traced on its surface, and each spark is marked on the line by a small bright dot whenever the current is broken.

There is another method of registration in which the circuits that are broken pass through the Marcel Drepez registers, *e*, Fig. 135. When the circuit is broken the magnet, *e*, Fig. 135, is demagnetized and the spring, *g*, rotates the armature, *f*, and its attached stylus or quill, *h*, thus making a bend or offset in the trace of the quill on the cylinder. The spark type of chronoscope wherein a splatter or bright dot on the lampblackened cylinder is made by

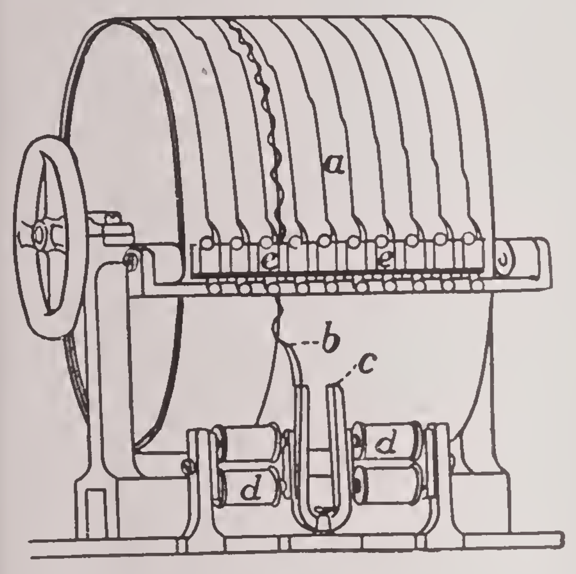


FIG. 134.

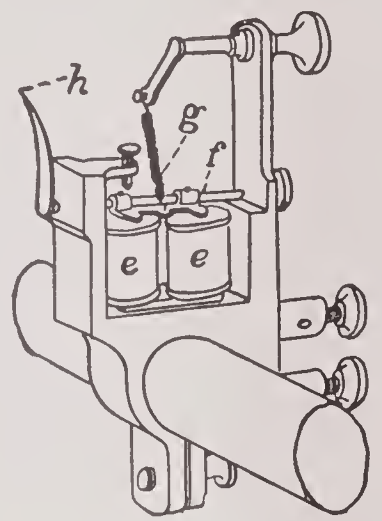


FIG. 135

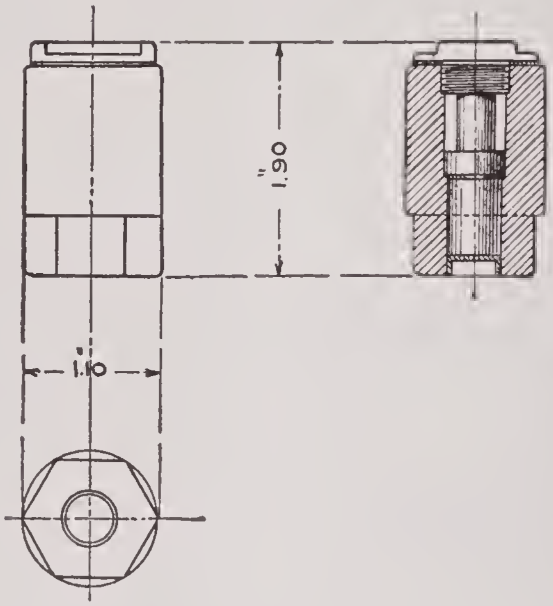
a spark instead of the offset by magnet, is used at the Naval Proving Ground, for the reasons that it is as accurate, more easily kept in repair, and is much easier to use.

The speed of the tuning-fork vibrations is nearly constant, being equal to about 250 per second. The distance between two sparks in terms of the vibrations would then measure 0.004 second. By means of a magnifying glass and micrometer the wave length may be divided quite accurately into 100 parts, thus permitting the determination of the time intervals of $\frac{1}{25,000}$ of a second.

MEASUREMENT OF PRESSURES.

802. Gauges.—Pressures in cannon are directly measured by means of the navy pressure gauge (Figs. 136 and 137, and Plate III). In a steel cylinder or housing is assembled a steel plunger and a copper cylinder or disk. The cylinder is closed by a screw cap, the joint being made tight by a copper washer.

A small copper obturating cap prevents the entrance of gas past the plunger, and the copper washer performs the same office at the joint between the cylinder and the screw cap.



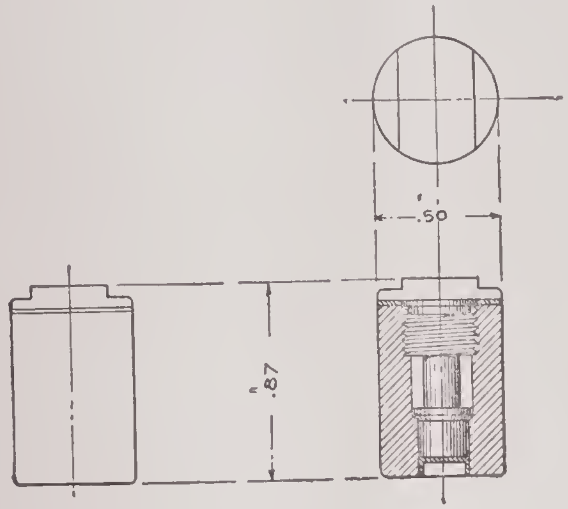
$\frac{1}{6}$ AREA PRESSURE GAUGE
SCALE $\frac{1}{2}$.

FIG. 136.

Gauges are placed in the gun behind the powder charge, or may be, in addition, inserted in sockets in the mushroom. Three gauges are also used. Those in the mushroom are generally used only in proving-ground work. When the gun is fired the pressure of the powder gases is exerted against the end of the plunger, and the copper disk is compressed. The compression is manifestly due to the maximum pressure exerted in the gun. The length of the disk is measured both before and after firing by a micrometer gauge, the compression due to pressure thus being determined. With this compression the pressure per square inch that produced

it is read at once from the compression curve furnished with each lot of disks.

803. The compression curve.—The copper disks are cut in a given length from rods very uniformly rolled and carefully annealed. The compression of the disks under different loads is determined in a static-pressure machine. It is assumed that the compression obtained in firing is due to a load on the plunger of the pressure gauge equal to the load that produced the same compression in the static machine. The pressure per square inch in



$\frac{1}{30}$ AREA PRESSURE GAUGE
SCALE $\frac{1}{2}$.

FIG. 137.

the gun may therefore be obtained by dividing the static load that corresponds to the observed compression by the area of the plunger in the pressure gauges. Knowing the area of the plunger used, the table of compressions and corresponding pressures per square inch is readily constructed from the results obtained in the machine.

The area of the plunger for large caliber gauges is one-sixth of a square inch (Fig. 136). The plunger for the 6-pounder and other minor caliber gauges has an area of one-thirtieth of a square inch (Fig. 137).

804. Initial compression.—When the pressure in the gun is high the compression of the copper is considerable, and the plunger acquires an appreciable velocity during the compression. The energy of the plunger due to this velocity adds to the compression that would result from the pressure alone, and consequently the measured compression is greater than the compression that corresponds to the true pressure. The energy of the plunger may be reduced either by reducing its weight or by limiting its travel and hence its velocity. The plunger is made as light as possible consistent with the duty it has to perform. To limit its travel the copper cylinders are initially compressed before using, by a load corresponding to a pressure somewhat less than that expected in the gun. Further compression of the copper will not occur until the load applied in the gun is close to that used in the initial compression.

The general practice is to give all the one-thirtieth area disks an initial pressure of 4 tons and all the one-sixth area disks an initial pressure of 9 tons per square inch.

805. The velocimeter measures the velocity of recoil of a gun, and is used in connection with a chronoscope. Its principal part is a drum rotated by a string made fast to the gun. Each two inches of recoil, by turning the drum composed of insulated segments, makes and breaks an electric circuit to the chronoscope. A strong spiral spring takes in the slack on the counter-recoil and keeps a good tension on the line, so that the drum moves according to the recoil of the gun at all times. On the rotating smoked drum of the chronoscope in the laboratory, each two inches of recoil, then, is marked by a spark formed by an interruption in the electric circuit as the segments of the drum are passed over. The number of vibrations of the tuning-fork on the chronoscope per second being known, by counting these vibrations between the successive sparks on the drum the velocity for every two inches of recoil is known.

Guns do not recoil as rapidly as might be imagined. Twenty feet per second, or 12 knots per hour, is a good maximum value. Counter-recoil velocities are about one-eighth of the value of recoil velocities. By studying the curve of recoil velocities in connection with recoil-cylinder indicator cards, abnormal stresses in the mount may be detected and avoided in design.

806. Aberdeen chronograph.—In this instrument the eletrical impulse recording the passage of the projectile through the screens

is a "make" in the circuit, instead of a "break" as in the Boulengé. The mechanism consists of a shallow aluminum cylindrical drum driven by a series-wound ball-bearing motor, at a constant speed of 25 revolutions per second, the speed being controlled by a governor acting through resistances in the full line voltage. The screens consist of two metal plates (tin or tinfoil) separated by an insulating sheet of paraffined paper. The circuit leads from one plate of the screen to the spark point held in an insulated block 0.5 mm. from the inner periphery of the drum and from the drum through a condenser back to the other plate. A strip of special paraffined paper is placed in the drum and held by centrifugal force against its inner periphery. When the projectile passes through the screen it completes the circuit, causing a spark to jump across from the spark point to the drum, perforating the recording paper. The spark points for each screen are vertically in line, hence the distance between marks on the paper, knowing the screen distance and speed of motor, represents the time interval between screens from which the velocity is determined. The instrument can be calibrated by means of a ball drop, *i. e.*, measuring the known time interval taken by a ball dropped from a given height.

807. Oscillograph.—This instrument is also used at the Proving Ground for measuring time intervals. It consists of a finely adjusted galvanometer, with exceedingly small period of free vibration, the movement of which is recorded by means of a beam of light on a moving film. Time is recorded on the same film, and through the same means, by a carefully calibrated tuning fork, actuated by an electrical impuse. The galvanometer loop is connected to separate circuits.

These circuits are connected (when used in velocity determinations) at various points of the projectile's travel, there being no current flowing except when the projectile passes that point. When this occurs a momentary circuit is set up which acts upon a sensitive galvanometer in the oscillograph. These galvanometers have small mirrors, which ordinarily remain in a fixed position, throwing a steady beam of light on the film, but are sharply deflected when the circuit is completed, with resultant sharp offsets at the points of the projectile's passage. The distance between these points, referred to the record of the tuning-fork vibrations, give the time interval between successive passages and hence the velocity of the projectile.

808. The gunner's quadrant consists of a flat base with a pivoted arm carrying a spirit level. The arm is set at the reading corresponding to the desired elevation, the quadrant is put on the gun, and the gun is elevated until the bubble centers. It is then at the desired elevation. (See Plate III.)

The Vickers gun clinometer is a more accurate instrument. The level arm is adjusted to the degree next below the elevation desired. By turning a screw handle, a needle arm on a large arc graduated to minutes is worked so that the setting of the instrument to degrees and minutes of elevation is done more quickly and more accurately than with the simple type of gunner's quadrant.

Droop may be expressed as the angle that the final tangent of the curved bore makes with the axis of the gun at the breech. To measure the inclination of the muzzle, a muzzle rest with two cylindrical disks or bearing surfaces is fitted snugly into the muzzle of the gun. On the central shaft of this device is placed a striding clinometer, lying parallel to the center line of the gun, which is leveled crosswise and also fore and aft with reference to the gun, by set-screws. In using this clinometer it is read, then reversed, end for end, and read again. Were the instrument perfect, the readings should agree. This is not generally the case, so the average of the two readings is taken to eliminate error. At the same time (the gun being approximately level) the elevation at the breech is taken with the Vickers clinometer (read both ways and averaged for the same reason). The difference between the elevation at the muzzle and at the breech is the *droop*. This should be only a few minutes of arc, even in the largest guns. (Plate III.)

The Tabor indicator is similar in all respects to those used on a steam engine, except that the piston area is $\frac{1}{20}$ square inch instead of $\frac{1}{2}$ square inch. This is used to get pressures of the liquid in the recoil cylinder. It is screwed in a threaded plughole in the recoil cylinder, and the string is atached to the gun or to the yoke. When the gun is fired, a card is made showing the pressure corresponding to any amount of recoil. These pressures run from 2000 to 3000 pounds for modern guns, and the general appearance of the curve—the presence of "peaks," etc.—shows whether or not the recoil system is behaving normally. (Plate III.)

CHAPTER XVIII.

AIRCRAFT, ANTI-AIRCRAFT, AND FIELD GUNS.

Aircraft Guns.

809. Guns for use in aircraft must be light and easily manipulated, and must have little or no recoil, since the structure of airplanes will not allow of any heavy shocks due to the discharge of guns mounted in them. The usual equipment carried by fighting planes consists of one or more machine guns, the latter being light, automatic in action, easily trained, and capable of the greatest rapidity of fire. Certain classes of aircraft carry other types of guns, firing a larger projectile and possessing greater destructive power. These range from one-pounder guns to six- and nine-pounder guns, the two latter being of a special type known as *non-recoil guns.*

810. The ordinary combat plane used by land forces carries only machine gun equipment, since it is used only in attacking other aircraft or exposed bodies of troops. Special mountings enable the gun to be quickly trained in any direction. For airplanes having a propeller at the forward end of the fuselage, a control gear is provided to synchronize the gun fire with the propeller, so that the gun may be fired directly through the plane of rotation of the blades without danger of striking them. This enables the machine gun operator to keep up a steady fire while flying or diving directly at the enemy. *Tracer bullets* are used, to assist him in bringing his shots on the target.

Instead of firing through the plane of rotation of the blades, shooting dead ahead is sometimes attained by enclosing the gun in the crank case and firing through the hub of the propeller. Obviously such a gun can be used only when the airplane is headed toward the enemy.

811. In the case of seaplanes, one important object is the destruction of enemy submarines. With this end in view, such aircraft are fitted to carry bombs, or else are armed with guns of a caliber sufficient to penetrate the steel hull of the submarine.

Plate I shows a six-pounder non-recoil gun such as is mounted in U. S. Naval airplanes. It will be seen to be a double-ended gun,

6-PDR. NON-RECOIL GUN WITH LEWIS MACHINE GUN POINTER.

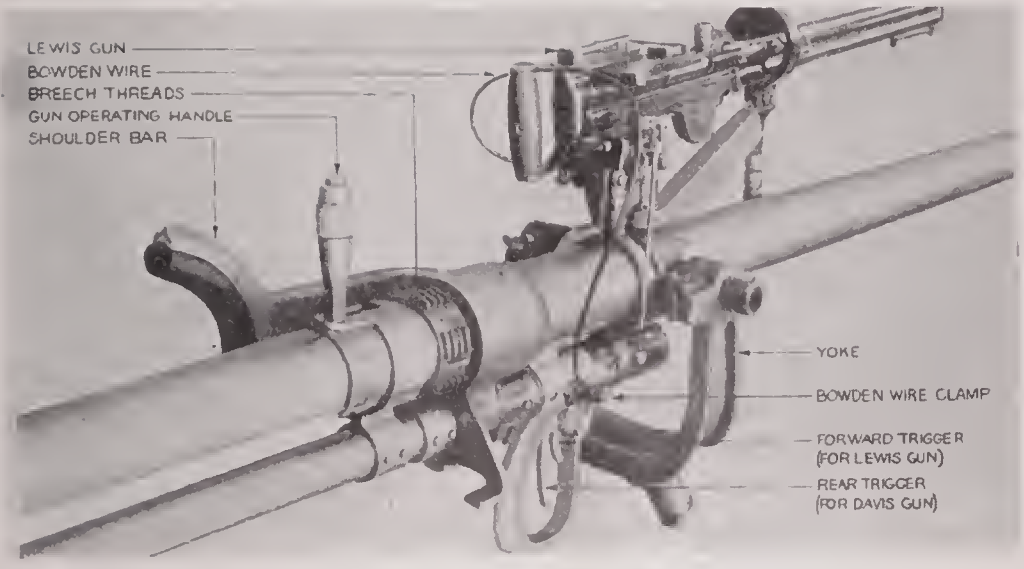


FIG. 1.—REAR BARREL UNSCREWED AND PULLED TO THE REAR READY TO ROTATE TO THE RIGHT. NOTE ALSO GENERAL ASSEMBLY.

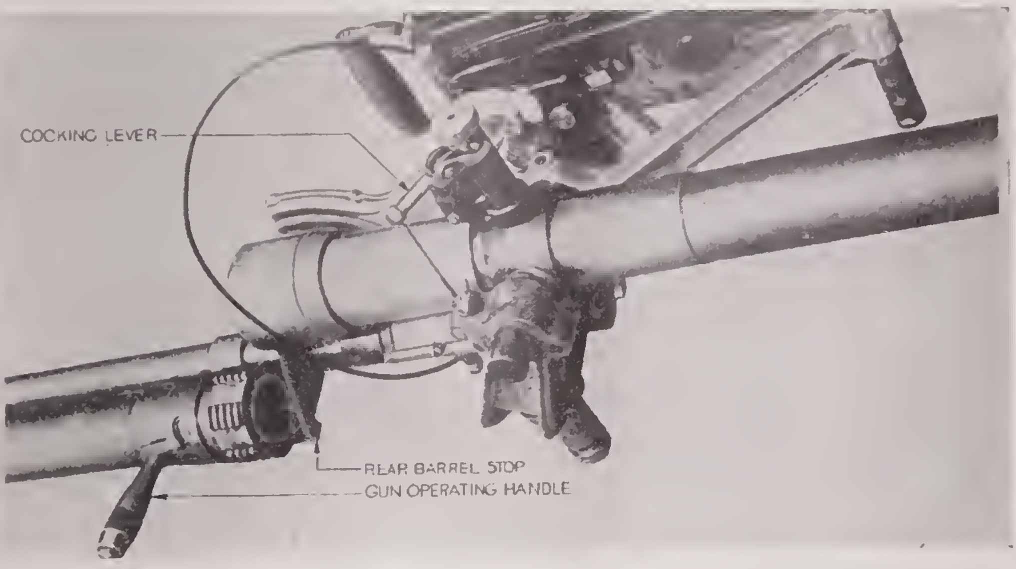


FIG. 2.—BREECH OPEN. NOTE POSITION OF GUN-OPERATING HANDLE AND COCKING LEVER.

6-PDR. NON-RECOIL GUN SHOWING DETAIL OF BREECH AND LEWIS MACHINE GUN POINTER.

in which the recoiling force of the forward barrel is counterbalanced by that of the rear barrel, from which a dummy charge is fired simultaneously with the projectile, this dummy charge consisting of fine shot. There is but one powder chamber; half of the powder may be considered as propelling the forward projectile, and the other half as propelling the dummy charge. The result is that one explosive force counteracts the other, and practically no shock of recoil is transmitted to the mount. The latter can therefore be made comparatively light, as is necessary in aircraft to eliminate weight, and in addition, little or no force is transmitted to the gun platform. Plate I shows not only the six-pounder gun and mount, but a superposed Lewis machine gun as well, and also the method of mounting and operating the gun in the cockpit of an airplane.

812. **The non-recoil gun** consists essentially of three parts: the *forward barrel*, the *rear barrel,* and the *group of working parts.* The latter includes the *operating handle,* the *rotating shaft*, and the *firing mechanism* and *attachments.*

The barrels are each formed of a single forging, the forward one being chambered at its breech end to take the special type of ammunition provided for these guns. (See Art. 675, Fig. 117, Chap. XVI.) Beyond the chamber, this barrel is rifled as in the case of other guns. Shrunk over its breech end is the *breech band*, on the inside of which are cut the usual type of interrupted screw threads. The rear barrel is not rifled, but is smooth-bored for its whole length. The breech end of the rear barrel (which in this case is its forward end) is threaded on the outside to conform with the threads on the inside of the breech band on the forward barrel.

Plate II furnishes a good idea of the parts of the gun, together with their operation in loading and firing. Fig. 1 shows the breech unlocked and the rear barrel drawn to the rear, ready for rotating to the open position as shown in Fig. 2. These operations are all performed by the gun "operating handle," which is secured to the rear barrel and slides in a bayonet joint slot in the "handle guide band." As is apparent from the type of screw thread used, about an eighth of a turn is sufficient to unlock the breech. This is accomplished by moving the operating handle to the right along its slot, after which it is drawn to the rear, thus withdrawing the threaded portion of the rear barrel from the screw box. In the next motion the rear barrel is rotated to the right, around the

"rotating shaft," until it rests on a small projection from the breech band of the forward barrel, in the position shown in Plate II, Fig. 2.

813. The rotating shaft extends underneath the gun (see Plates I and II) and serves as a bridge between the forward and the rear barrels. It is rigidly secured to the two guide bands surrounding the rear barrel, but is free to turn in its bearings in the breech band and the trunnion band on the forward barrel, thus providing a means for rotating the rear barrel to one side when loading the gun.

814. The *pistol grip, the trigger, the firing rod and springs*, and the *cocking cam* are all carried by the rotating shaft. Fig. 138

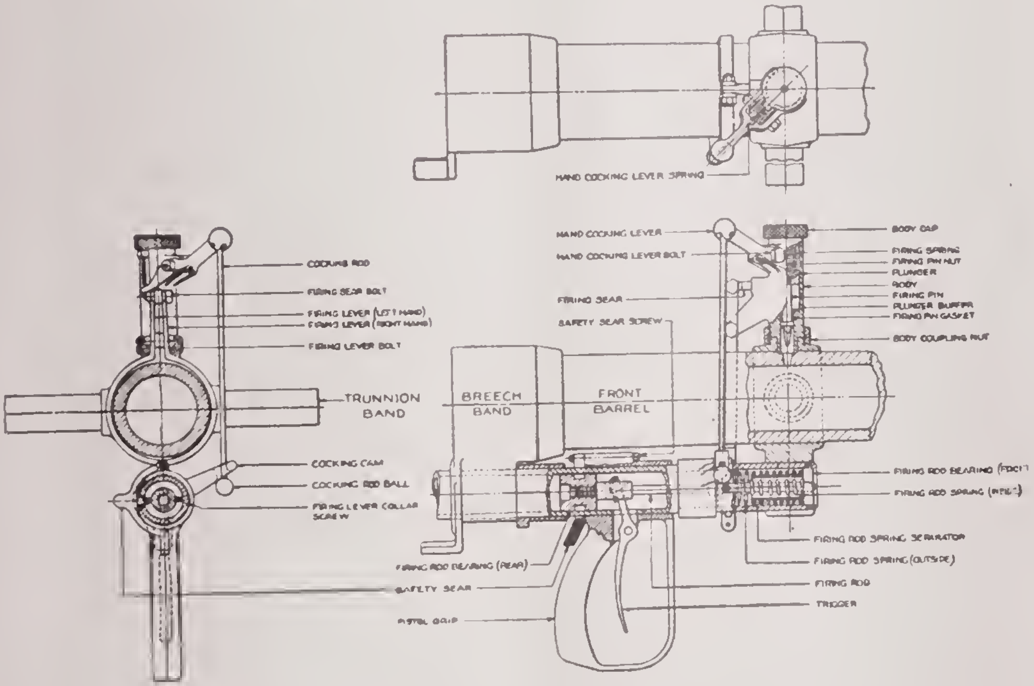


FIG. 138.—MECHANICAL DETAILS OF FIRING MECHANISM AND ATTACHMENTS.

shows the arrangement of these attachments, together with the *firing levers* and the *firing mechanism body*, which latter contains the *sear*, the *plunger*, the *firing spring*, and the *firing pin*.

The rotating shaft also carries an *extractor cam*, not shown in Fig. 1, which actuates the *extractor* and withdraws the shell on opening the breech.

815. Operation.—The mechanical details of the gun can probably be better understood by a description of its operation during loading and firing.

Consider the gun as having just been fired:

To open the breech, the operating handle is raised slightly upward and rotated to the right about an eighth of a turn. This turns the rear barrel about its own axis as a center, and unlocks the breech bayonet joint. The handle is then pulled straight to the rear, thus sliding the rear barrel clear of the forward barrel. The rear barrel is then rotated about the rotating shaft as a center, leaving the breech clear.

Extracting the empty shell.—The turning of the rotating shaft about its center also turns the extractor cam, and forces the extractor about a quarter of an inch to the rear. This serves to loosen the empty case, after which it can be removed by hand.

Cocking the firing mechanism.—Rotating the shaft about its center as an axis also rotates the cocking cam, the motion of which is transmitted through the cocking rod to the cocking lever at the top of the firing-mechanism body. The cocking lever lifts the firing-pin plunger and compresses the firing-pin spring. When the plunger is raised above the end of the firing sear, the latter is pressed forward by the firing-rod springs (acting through the firing levers), and holds the firing pin and plunger in the cocked position. At this point the *safety sear,* shown in Fig. 138, is pushed to the right with the thumb, thus locking the firing mechanism in the cocked position.

Loading.—The gun is then loaded, care being taken that the "locating boss" on the end of the cartridge case fits into the locating groove in the breech band.

To close the breech, the operations in opening are reversed. The rear barrel is rotated to the left about the rotating shaft, and is then slid forward into the screw box. The next movement rotates it to the left about its own center as an axis, and locks the breech.

Firing action.—The safety sear is pushed to the left, and the trigger is then pulled. The trigger being pivoted near the center, a pull to the rear at the lower end presses the upper end forward, moving the firing rod forward and compressing the firing-rod springs. The forward motion of the firing rod carries forward also the lower ends of the firing levers. The latter being pivoted near the upper end by the *firing-lever bolt*, this forward motion of the lower end causes the upper end to move to the rear, withdrawing the sear and releasing the firing-pin plunger. Thereupon the

firing pin is driven downward by the firing-pin spring, striking the primer and firing the gun.

816. Machine gun pointer for non-recoil guns.—Owing to the difficulty of aiming a single-shot gun from a moving airplane, and making the proper allowance for speed of the plane, etc., a machine gun, as shown in Plates I and II, is mounted on the non-recoil gun to act as a pointer.

Suppose the airplane is firing at a target in the water. By observing the splash of the machine-gun bullets, proper correction of the aim can be made, and the larger gun can then be fired as the line of small splashes comes on the target. Both triggers are in close proximity, so that either or both can be pressed without changing the position of the hand.

It will be noted that the machine gun can be set at a different angle of elevation from that of the non-recoil gun. This provision is imperative, due to difference in the trajectories of the two kinds of projectiles, which makes necessary a certain super-elevation of the machine gun over the larger gun. *Theoretically*, this super-elevation, it has been determined, depends on two factors; first, the "ground speed" of the airplane, and secondly, the angle at which the non-recoil gun is fired. Tables have been made out showing the angles of super-elevation for different ground speeds and angles of fire. Having determined the angle at which the non-recoil gun is to be fired, and having ascertained or estimated as closely as possible the ground speed of the airplane, the machine gun is set to the proper angle of super-elevation. When the target is sighted, the plane is flown toward it. As soon as the target appears on the line of sight of the non-recoil gun, the gunner opens fire with the machine gun and observes the location of the splashes. Due to the motion of the airplane these splashes will appear as a line, and the gunner trains both guns so that the line of splashes will cross the target. The instant a splash appears on or close to the target he fires the larger gun.

In practice, the method of calculating the angle of super-elevation of the machine gun described above is not adhered to. Instead, the angle of fire of the non-recoil gun is taken as constant; the designed "*air* speed" of the plane is used; and the corresponding angle of super-elevation is permanently set before the gun is mounted in the airplane.

FIG. 1.—3-INCH 50-CALIBER ANTI-AIRCRAFT GUN AND MOUNT.

FIG. 2.—3-INCH 50-CALIBER ANTI-AIRCRAFT GUN AND MOUNT.

Anti-Aircraft Guns.

817. Guns to be used against aircraft must be capable of very high angles of elevation. The different types used in the navy, for instance, have angles of elevation varying from 75° to 90°. They must also have as great an arc of train as possible. For this reason, coupled with their extreme elevation, they are located at favorable points on the upper decks, on platforms on the cranes, or on top of the high turrets aft, where they are clear of the blast of turret guns.

Certain other features are striven for in the design of anti-aircraft guns. They include (1) ease and rapidity of elevating and training, (2) rapidity of loading and firing, (3) high muzzle velocity, and (4) caliber large enough to produce a good-sized shrapnel or high-explosive burst in the air. Obviously these features cannot all be attained in one gun, as some of them are diametrically opposed to each other. It requires a compromise, which in our navy has resulted in the adoption of a 3-inch 50-caliber semi-automatic gun, with a muzzle velocity of 2700 f. s., as the type of gun for the anti-aircraft battery of battleships and battle cruisers.

818. Plate III shows the 3-inch 50-caliber anti-aircraft gun and mount. As will be noted, the trunnion height is considerable—about 66 inches—and the mount is cut away at the rear to allow for 90° extreme elevation. Located on the upper deck, the gun is capable of training through 360° and, except over small arcs where the masts and stacks may interfere, it can be fired at all angles of train.

The gun proper consists of four parts, viz., the *tube*, the *jacket*, the *breech housing* and the *locking ring*. The jacket, which is shrunk over the tube, extends only part way to the muzzle. Over its forward end, and covering the joint between it and the tube, is screwed the small C-1 locking ring. The breech end of the jacket is threaded on the outside to receive the breech housing, which is screwed and shrunk over the breech of the gun, and is slotted to receive the breech block. The gun is fitted to use fixed ammunition only, and is rifled with rib rifling, increasing twist.

The breech mechanism is of the *sliding-wedge* type, and is semi-automatic in action. (See Art. 484 and Chapter XI, Plate V.)

The mount.—The various details of the mount are quite clearly shown in Plate III. It will be seen that the *carriage*, which forms the greater part of the mount, rests over a low, cylindrical *stand* that is bolted to a foundation plate in the deck. The actual bearing surface on which the weight of the carriage and gun is taken is a ball-race, designed to reduce friction to a minimum. Extending around the upper part of the stand, and rigidly secured to it, is the *training rack*. Neither the rack nor the ball-race is visible, because they are obscured by the overhang of the carriage. A *training pinion*, meshing with the training rack, is connected by a suitable shaft and gearing with the trainer's two-hand drive shown at the right of the gun.

On the left-hand side of the carriage is the pointer's two-hand drive, which actuates a pinion meshing with the *elevating arc* shown in Fig. 2. The right handle of this drive gear is fitted as a firing handle. It is operated by a quick turn of the pointer's wrist, which throws the handle over to one side and then back to the normal position again.

At the top of the carriage are the trunnion seats in which the trunnions rest. The latter form part of the slide through which the gun slides on recoil and counter-recoil.

The recoil cylinder is located above the gun instead of underneath, in order to allow for greater angle of elevation. It contains, besides the recoil piston and liquid, the counter-recoil springs for forcing the gun back again to battery. The piston rod, it will be seen, is secured to a lug on top of the breech housing.

Prismatic telescopic sights are provided for this gun, so that the pointer's position at the telescopes will be comfortable even when the gun is at a high angle of elevation. The sights are carried on a sight yoke that pivots on the slide just forward of the recoil cylinder bonnet. The sight bar extending to the rear, the deflection arc and deflection drum, the graduated sword and the range drum, together with the knurled heads for setting range and deflection, are all shown with sufficient clearness in Plate III to be readily understood.

Fig. 1 shows a gun rigged with dotter gear for pointer drill. Fig. 2 shows the flexible metal voice tube by which ranges and battle orders are transmitted to the gun. This tube is coupled to a brass voice tube extending through the base of the mount to the

deck below. Fig. 2 also shows the wiring for sight lighting in case of firing at night.

Ammunition.—The ammunition used with the 3-inch 50-caliber anti-aircraft gun is of two kinds:

1. Shrapnel, for defence against aircraft.
2. Non-ricocheting loaded shell for defence against submarines.

Obviously the latter type of shell has nothing to do with aircraft. The guns, however, from their favorable location and the readiness with which they can be handled, were found to be valuable anti-

819. Other anti-aircraft guns.—The anti-aircraft gun just described is not the only one in use in the navy. There is a 3-inch 23-caliber gun of lower muzzle velocity for mounting on destroyers, sub-chasers, and certain other types of vessels. In addition, a one-pounder automatic gun has been used to a rather limited extent. Still other types have been designed and may be submarine weapons, and in consequence were provided with the necessary ammunition for this purpose.
put in service, but the 3-inch 50-caliber gun is considered representative of the class, and a knowledge of it will give a fair idea of all other anti-aircraft guns.

Field Guns.

820. The field guns carried by U. S. ships for operations on shore consist of *machine guns* and 3-*inch field pieces.*

821. Machine guns are automatic rifles, firing the same ammunition as the .30 caliber service rifle. The various types in existence are provided with the necessary mechanism for loading a live cartridge into the barrel, firing it, automatically ejecting the empty case and loading in another cartridge, and continuing the cycle so long as ammunition is fed to the gun and the trigger held to the rear.

The energy for operating the mechanism is obtained in some machine guns from the recoil of the gun. In other types, a portion of the powder gases that propel the bullet is utilized for this purpose. Such guns have a small *gas port* near the muzzle end of the barrel, communicating with a *gas chamber* underneath. In this chamber is a piston on which the gases impinge at every shot, driving the piston to the rear against a spiral spring. The latter, being then under compression, forces the piston forward again as soon

HEAVY BROWNING MACHINE GUN, WATER-COOLED, ON TRIPOD MOUNT.

as the powder pressure has been relieved; and from the motion of the piston back and forth in the gas chamber the required operation of the mechanism is obtained.

822. Plate IV shows the "*heavy Browning machine gun, water-cooled,*" mounted on a tripod mount. It is so designated to distinguish it from the "*light Browning,*" which is designed to fire from the shoulder, and from the "*air-cooled Browning*" used in airplanes. This gun is of the type that utilizes the recoil to operate the automatic mechanism. As viewed from the outside, it consists of a *gun frame* enclosing the working parts, a *barrel,* surrounded by a *water jacket* for cooling purposes, a *front* and a *rear sight,* the latter being of the *sliding-leaf* type, a *grip,* and a *trigger.* Extending through the gun, just in rear of the water jacket, can be seen the *feed slot* through which is fed the cartridge belt. At each shot the belt is advanced the width of one pocket, a cartridge is withdrawn from the belt by suitable mechanism, and is fed into the chamber of the gun to continue the firing.

823. The working parts of the gun consist of the *bolt,* the *locking mechanism,* the *firing mechanism,* and the *driving mechanism.* Of these, the bolt is the most important, as well as the most complex, part. It acts as a breech closure or "fermeture" during firing; it receives the recoiling force of the gun, and upon being released by the "locking mechanism" after firing, slides to the rear against a *recoil buffer,* at the same time compressing a counter-recoil spring that drives it forward again to close the breech; it provides means for feeding the cartridge belt forward after each shot; it carries an *extractor* that withdraws a live cartridge from the belt and loads it into the chamber, and an *ejector* that throws the spent case clear of the gun. In addition, it carries a portion of the firing mechanism.

Plate V shows the working parts of the Browning machine gun. In Fig. 1 the bolt (1) is shown in its forward or firing position, resting over the *barrel extension* (28) and closing the breech. In this position a *breech lock* extends upward from the barrel extension, engaging behind *recoil shoulders* in the under surface of the bolt, thereby locking the bolt to the barrel and barrel extension during firing. The breech lock cannot be seen in the photograph, but the *breech lock pin* (31) secured to it is shown protruding from a slot in the side of the barrel extension. Just above

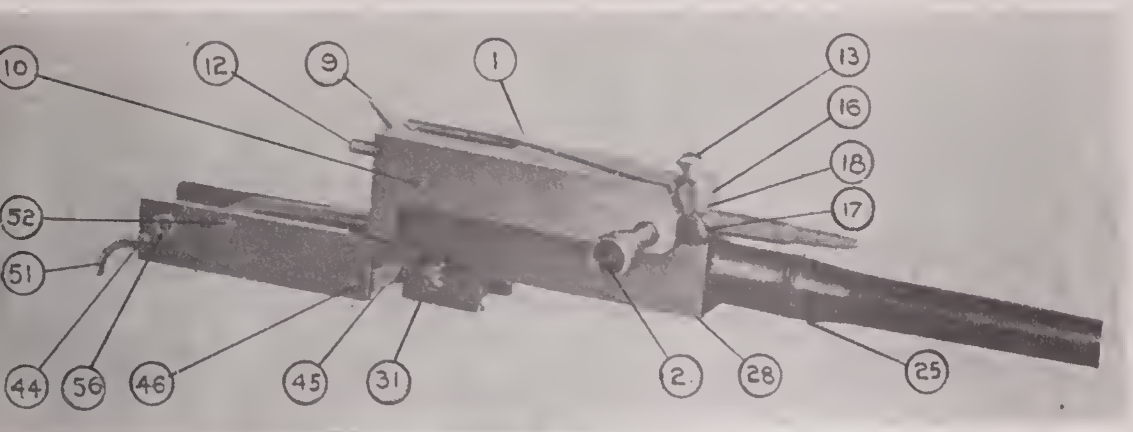


FIG. 1.

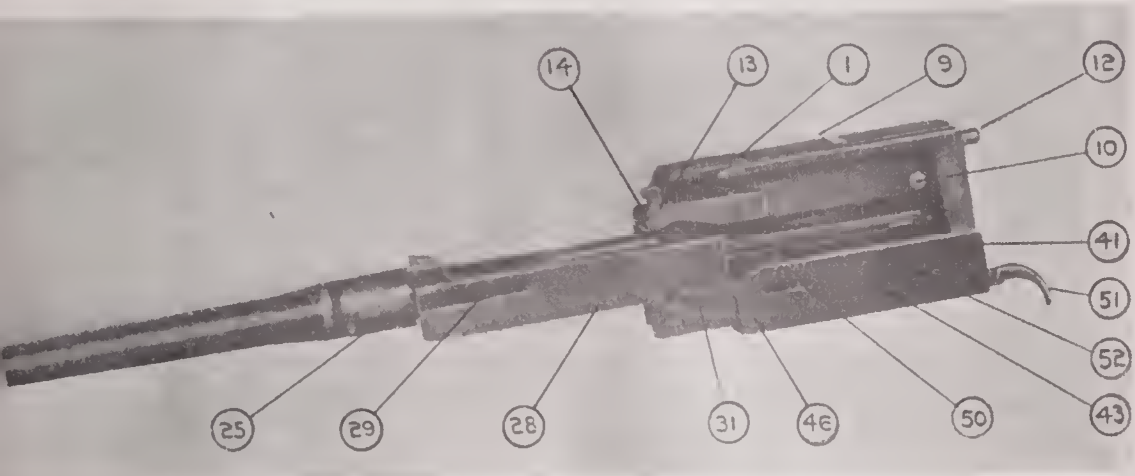


FIG. 2.

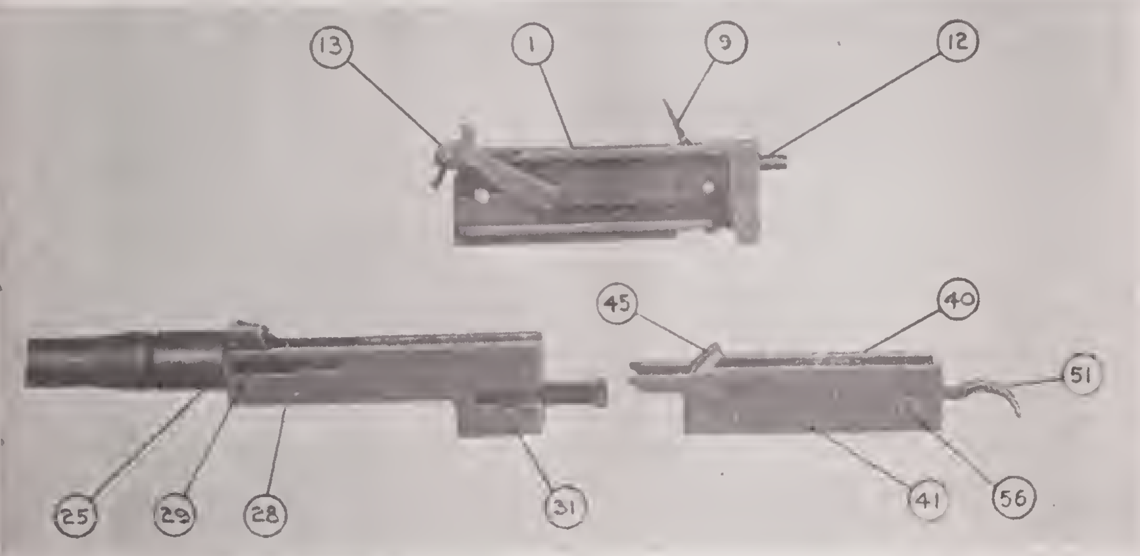


FIG. 3.

BREECH MECHANISM, BROWNING MACHINE GUN.

1. Bolt.
2. Bolt Handle.
9. Cocking Lever.
10. Cocking Lever Pin.
12. Driving Spring Rod.
13. Extractor.
14. Extractor Cam Plunger.
16. Extractor Cam Plunger Pin.
17. Ejector.
18. Ejector Pin.
25. Barrel.
28. Barrel Extension.
29. Barrel Locking Spring.
31. Breech Lock Pin.
40. Lock Frame (right hand).
41. Lock Frame (left hand).
43. Lock Frame Rivet.
44. Lock Frame Guide Pin.
45. Accelerator.
46. Accelerator Pin.
50. Barrel Plunger Guide Pin.
51. Trigger.
52. Trigger Pin.
56. Lock Frame Spacer Rivet.

the barrel a cartridge is shown, held between the extractor and the ejector in the manner in which it is withdrawn from the belt. At the side of the bolt is the *bolt handle* (2), used in drawing the bolt to the rear by hand for the first shot.

Fig. 2 shows the parts of the gun in the recoiled position. The bolt is seen to be almost clear of the barrel extension, and resting on the *lock frames* (40 and 41). The extractor, in this position of the bolt, has been forced downward by a cam surface in the cover of the gun, so that the cartridge it carries is now properly pointed to slide into the chamber. A portion of the cartridge case can be seen in the groove in the top of the barrel extension.

Attention is called to the difference in location of the barrel extension, with respect to the lock frame, in Figs. 1 and 2. In Fig. 1, which shows the firing position of the various parts, the barrel extension is separated from the lock frame a little more than half an inch, whereas in the recoiled position, shown in Fig. 2, the barrel extension and lock frame are in contact. The reason is this: the barrel and barrel extension recoil with the bolt a short distance after firing. As previously noted, the bolt is locked to the barrel extension at the instant of firing. Obviously it must remain locked for a fraction of a second thereafter, while the bullet travels down the bore; consequently provision is made for all three parts to recoil together. It will be seen in Fig. 1, however, that the *breech lock pin* (31) very shortly passes under the beveled end of the lock frame, which forces the pin down and causes the breech lock to disengage from the shoulders in the under side of the bolt. (In Fig. 2 it will be noted that this has happened.) The bolt then slides to the rear freely, receiving an added impulse in that direction from the *accelerator* (45) (shown in Fig. 3), which communicates to the bolt the residual recoiling energy contained in the barrel and barrel extension.

Since the bolt recoils with considerable force, means must be provided to absorb the shock of impact as it is brought to rest in its extreme rearward position. The bolt strikes against a *buffer plate* at the forward end of the grip, from which the shock is transmitted to a cushion composed of fiber washers inside the grip, thus stopping the bolt without undue strain or jarring of the gun. As the bolt slides to the rear during recoil, it compresses a counter-recoil spring known as the *driving spring*, and in so doing stores

up energy sufficient to force it back to its firing position. As soon, therefore, as it comes to rest against the buffer, the driving spring forces it forward again to the position shown in Fig. 1. At the same time, the barrel and barrel extension are driven forward to their firing position by the *barrel plunger* and *plunger spring,* located between the right and left lock frames.

824. Only a part of the firing mechanism of the gun is visible in the figures. The mechanism consists of a *trigger* (51), a *cocking lever* (9), a *sear* and *sear spring,* a *firing pin* and *firing-pin spring.* The function of the cocking lever is to draw the firing pin to the rear, at the same time compressing the firing-pin spring. In its retracted position the firing pin is held by the sear until the trigger is pressed, when it flies forward against the primer. This action is brought about as follows: The long arm of the cocking lever extends through a hole in the top plate of the gun frame. In the position shown in Fig. 1, the firing pin has been released and has struck the primer, thus firing the gun. The bolt recoils, carrying with it the cocking lever. In so doing, the long arm of this lever comes in contact with the after edge of the hole in the top plate, causing the lever to pivot about its fixed point to the position shown in Fig. 2. At the same time, the short arm of the lever is thrown in the opposite direction, drawing with it the firing pin. The latter is drawn back until its head rests in a notch in the sear, which locks it in that position until the sear is pulled downward by pressing the trigger. As the bolt slides forward after recoil, the long arm of the cocking lever strikes the forward edge of the hole in the top plate, causing it to pivot again to the position shown in Fig. 1, ready to repeat the operation of cocking the gun. If the trigger is pressed continuously the gun fires automatically each time the long arm of the cocking lever is thrown to the rear.

825. In a previous paragraph, the statement was made that the cartridge belt is fed through the feed slot by the action of the bolt. The actual mechanism involved in this operation consists of the *belt feed slide* which moves back and forth in its grooves in the cover of the slot, and the *belt feed pawl* which is carried on the slide. The pawl acts as a ratchet, moving the belt forward one cartridge width with each complete cycle of operations of the gun. The reciprocating motion of the slide is obtained through

the *belt feed lever,* which is pivoted at its center in the cover of the gun frame, and has at one end a lug that follows the diagonal *cam groove* shown in the top surface of the bolt. As the bolt slides back and forth in an axial direction, the arms of the belt feed lever are forced to move back and forth in a transverse direction, thus giving the desired motion to the belt feed slide.

826. The water jacket surrounding the barrel of the gun is for the purpose of cooling the barrel, which would otherwise become very hot due to continuous firing. The jacket consists of a steel cylinder, threaded at each end, the forward end screwing on to the *end cap* and the after end to the *trunnion block.* The joints in each case are sweated together. A bearing, packed with asbestos to make it water-tight, is provided for the barrel in the end cap. A similar bearing for the barrel and barrel extension is located in the trunnion block.

At the top of the water jacket, near its after end, is a filling hole. A drain hole is located in the bottom of the end cap. Each of these holes is closed by a screw plug, fitted with a chain fastening to prevent its being lost.

A steam vent is provided in the end cap to allow for the escape of steam as the water becomes heated. This vent is connected with an *inner* steam tube within the water jacket, which tube has two holes in its upper surface, one near each end. An *outer* steam tube, somewhat shorter than the inner tube, slides over the latter, automatically covering whichever hole happens to be at the lower level. In this way, water is prevented from escaping, steam only being allowed to pass out of the vent in the end cap.

827. **Operation of the gun.**—The following description is given of the action of the gun during a firing cycle:

Backward motion.—With the gun loaded and in the ready-to-fire position, the trigger is pressed. The forward end of the trigger, being engaged with the sear, causes the sear to slide downward in its groove in the rear end of the bolt against the lifting action of the sear spring. This releases the firing pin from the sear notch, and the firing pin is driven forward by the force of its spring until it strikes the primer and fires the gun.

The barrel, barrel extension, and bolt then recoil together. After traveling about half an inch they are unlocked, the rearward motion of the barrel and barrel extension is arrested, and the bolt

continues to the rear. During its travel, energy is stored up in the driving spring for the counter-recoil movement.

The backward motion of the barrel and barrel extension after unlocking is gradually transferred to the bolt through the accelerator, which functions as a steadily increasing lever bearing against the lowest portion of the rear of the bolt. The accelerator gains momentum as it swings rearward, and imparts an accelerated motion to the bolt, so that the latter will complete its backward motion against the action of the driving spring. The accelerator also holds the barrel and barrel extension in their rearward position until the bolt returns and forces the top edge of the accelerator forward, thus unlocking the barrel extension from the lock frame.

At the beginning of the backward motion of the recoiling parts, the extractor starts a cartridge from the feed belt. When the bolt is unlocked from the barrel extension and starts to travel rearward, a " T "-cut in the front part of the bolt draws the empty cartridge case from the chamber. As the end of the case clears the after end of the chamber, the shell falls out, or is forced out by the ejector. At the same time, the new cartridge is lowered to position.

During the rearward movement the cocking lever, playing between the two shoulders in the top plate, cocks the firing pin against the action of the firing-pin spring. It is held cocked by the sear.

From the beginning to the end of the backward motion the feed lever slowly moves the belt feed pawl to the left, so as to engage the next cartridge in the belt.

The backward motion of the bolt is limited by the bolt striking the buffer plate.

Forward motion.—The bolt starts forward under the action of the driving spring. The feed lever moves another cartridge over into the feedway. The live cartridge, that was carried to the rear by the extractor during recoil, is placed in the chamber, and the extractor is raised into position to extract the new cartridge just put into the feedway.

As the bolt nears the limit of its forward movement, the lower rear lugs again come in contact with the accelerator, swinging it forward on its pivot. This gradually slows up the forward motion of the bolt and, at the same time, releases the barrel and barrel extension, which then move to their forward position with the bolt.

The barrel plunger spring comes into play at this point and assists the driving spring in picking up the added weight of the barrel and barrel extension. While going forward, the breech lock is raised by the sloping surface of the breech-lock cam until the lock engages behind the recoil shoulders on the bottom of the bolt. This action locks the breech.

The sear, being attached to the bolt and moving with it, can engage with the trigger only when the parts are in their forward firing position; consequently the firing pin cannot be released before the breech is locked. If pressure on the trigger is maintained continuously, the cam surfaces on its forward end engage with similar surfaces on the sear and release the firing pin at the proper time, so that the gun fires automatically until the trigger is released.

3-Inch Landing Guns.

828. Landing guns supplied to U. S. Naval vessels are all 3-inch guns, 23 calibers in length, with a muzzle velocity of 1650 foot-seconds. They are mounted on mobile carriages, each gun being provided with a limber for the transport of ammunition.

Plate VI, Figs. 1 and 2, shows the 3-inch landing gun Mark IV, at present supplied to all battleships. The gun consists of a forged steel barrel, with two hydraulic recoil cylinders in one with it. The latter are located one on each side of the barrel, a little below the axis of the bore of the gun.

The gun and recoil cylinders *rest on* (not in) the slide, the former being provided with two *gibs* which fit under the edges of the slide and hold the gun to it during recoil. The top plate of the slide is made to conform to the contour of the gun, and forms a smooth bearing surface for it during recoil and counter-recoil. The slide itself rests on, and is pivoted to, a *turntable,* which in turn pivots on the axle and is movable vertically.

The *trail* is built up of steel plate and has bearings for the axle in its forward end. At its rear end is the *spade,* with the *trail eye* cast in it. A *trail wheel,* for use in transporting the piece, is removed in action, allowing the spade to be imbedded in the ground to prevent movement of the carriage to the rear on recoil. Secured to the side of the trail is the combination rammer and sponge, with the handle to be used with same. The *trail handles* and the loop for securing the *drag-rope snap hook* are riveted to the trail near its after end.

The carriage is provided with two wheels, to support the gun and to transport it from place to place. Two ammunition boxes, each containing 12 rounds, are carried on the carriage directly over the axle. Below them are the tool boxes.

The *elevating gear,* consisting of the *elevating wheel,* the *screw case,* and the *inner* and *outer screws,* is shown in section in Fig. 4, Plate VI. By turning the elevating wheel, the *shaft* and the *pinion* secured to it are turned. This causes the screw case to revolve, which transmits motion to the outer screw and thence to the inner screw, raising or lowering it, depending on the direction in which the elevating wheel is turned. By so doing, the gun is depressed or elevated.

A *traversing gear,* consisting of a *traversing screw* operated by two handwheels, provides a limited amount of lateral motion to the slide. A total train of 10° can be obtained in this way. For greater angles of train, the spade must be lifted and the gun slewed around by means of the trail.

829. The recoil system consists of two hydraulic recoil cylinders, both of which are integral with the gun and recoil with it, and two pistons and piston rods, the latter being secured to the *front enforcement* at the forward end of the slide. Each cylinder is fitted with a filling plug and a drain plug. An equalizing pipe connecting the two cylinders insures an equal amount of liquid in each of them.

Fig. 3, Plate VI, shows a longitudinal view of a recoil cylinder in section. It will be seen that the cylinder contains, in addition to the recoil piston and liquid, the counter-recoil springs as well. The latter consist of three sets of inner and outer springs, with *spring separators* between each set.

The piston rod, it will be observed, is hollow bored for about half its length from the rear face of the piston. This bore is known as the *throttling-bar socket.*

The piston carries the *throttling ring,* screwed into its rear end. Forward of the throttling ring is a recess called the *piston throttling chamber,* which is connected by means of *port holes* to the *piston annular groove.* The piston is allowed a .005-inch clearance in the cylinder, and has a shallow annular groove around it to give the effect of liquid packing during recoil. At its forward end is the *spring collar,* against which the springs bear. This collar is slightly

smaller in diameter than the bore of the cylinder, to allow free passage of recoil liquid from the cylinder to the piston annular groove and thence through the port holes to the throttling chamber.

Extending into the throttling-bar socket in the piston rod is the *throttling bar*. The latter bears on its after end the *throttling-bar nut,* which screws into the rear end of the recoil cylinder. The throttling bar is slightly shorter in length than its socket. It tapers gradually for the greater part of its length, then jumps to a slightly larger diameter in a quick slope, and is cylindrical for the remainder of its length. The throttling bar passes through the coned throttling hole in the throttling ring, then through the throttling chamber, and slides in the throttling socket. There are 90 throttling-bar socket *escape holes* drilled through the piston rod. These holes allow the free passage of liquid to and from the socket, and serve also to check the counter-recoil. At full counter-recoil, the forward end of the throttling bar is about .2 inch forward of the last escape hole, and the rest of the socket serves as a *dash pot.*

Checking of the recoil is accomplished by forcing the liquid from the cylinder through the piston port holes into the throttling chamber, and then through the tapered hole of the throttling ring, around the throttling bar. The clearance at this point is large at first, and allows an easy recoil. The tapered throttling bar, however, gradually closes the hole in the throttling ring, and, with the help of the springs, checks the recoil. The springs then return the gun to battery.

A special packing is provided at the front cylinder head to prevent the escape of liquid around the piston rod. There is first the annular V packing, backed by a packing ring sliding in the bore of the cylinder head. This is followed by a ring of hemp packing, which is pressed in place by the cylinder-head gland. Four holes in the cylinder head admit liquid to the V packing. The pressure of this liquid serves to set the packing against the piston rod during recoil and prevents leakage of the recoil liquid.

830. The sight provided with this gun consists of a peep sight, with ordinary cross-wires in the front sight. There is also an auxiliary finding sight, consisting of a notch on top of the peep sight and a point on top of the front sight.

Plate VII shows a later type of 3-inch landing gun. It is provided with a shield, and has a *split trail* to allow for high angle of

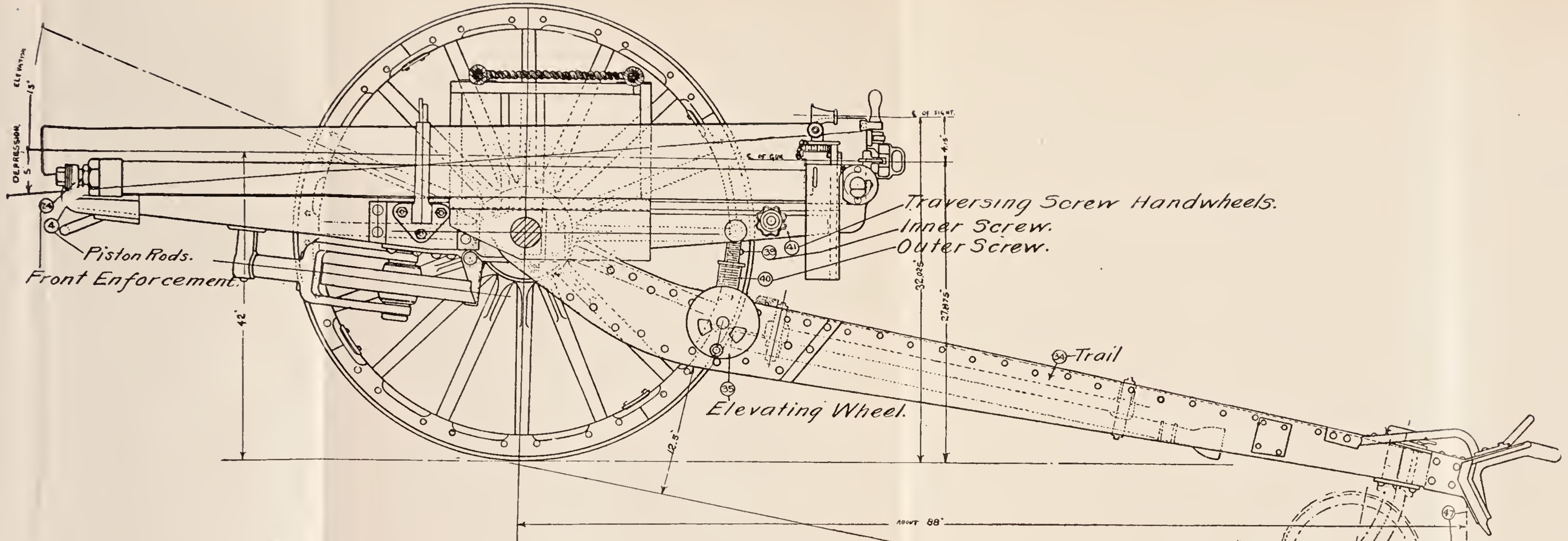


Fig. 1.

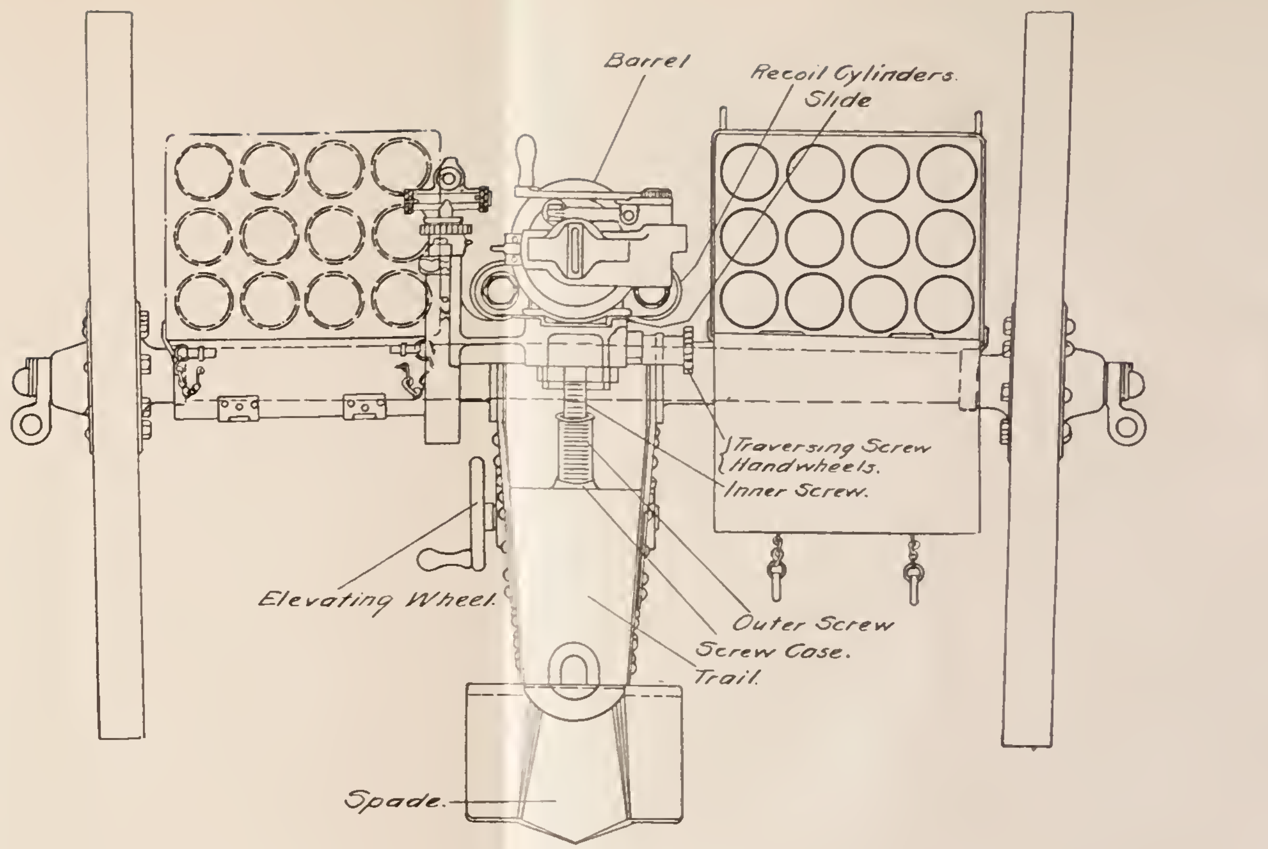


Fig. 2.

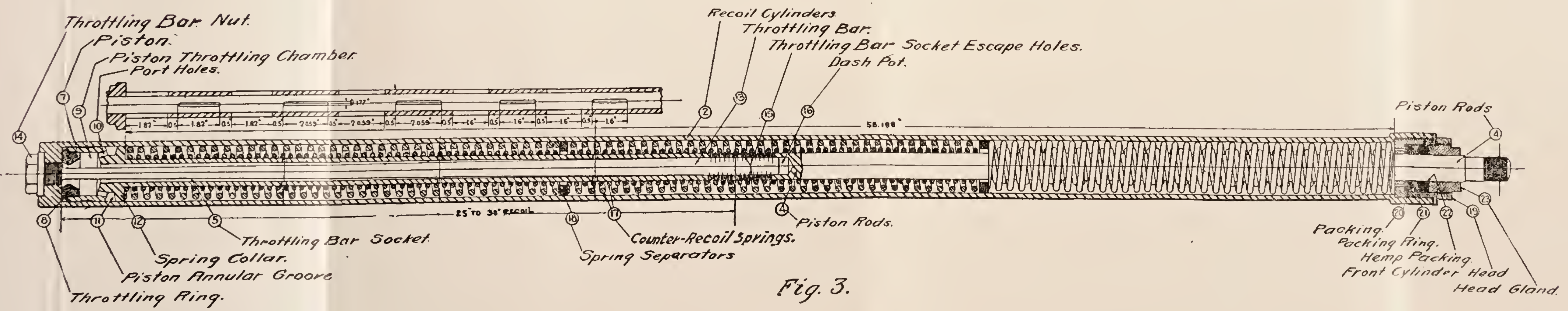


Fig. 3.

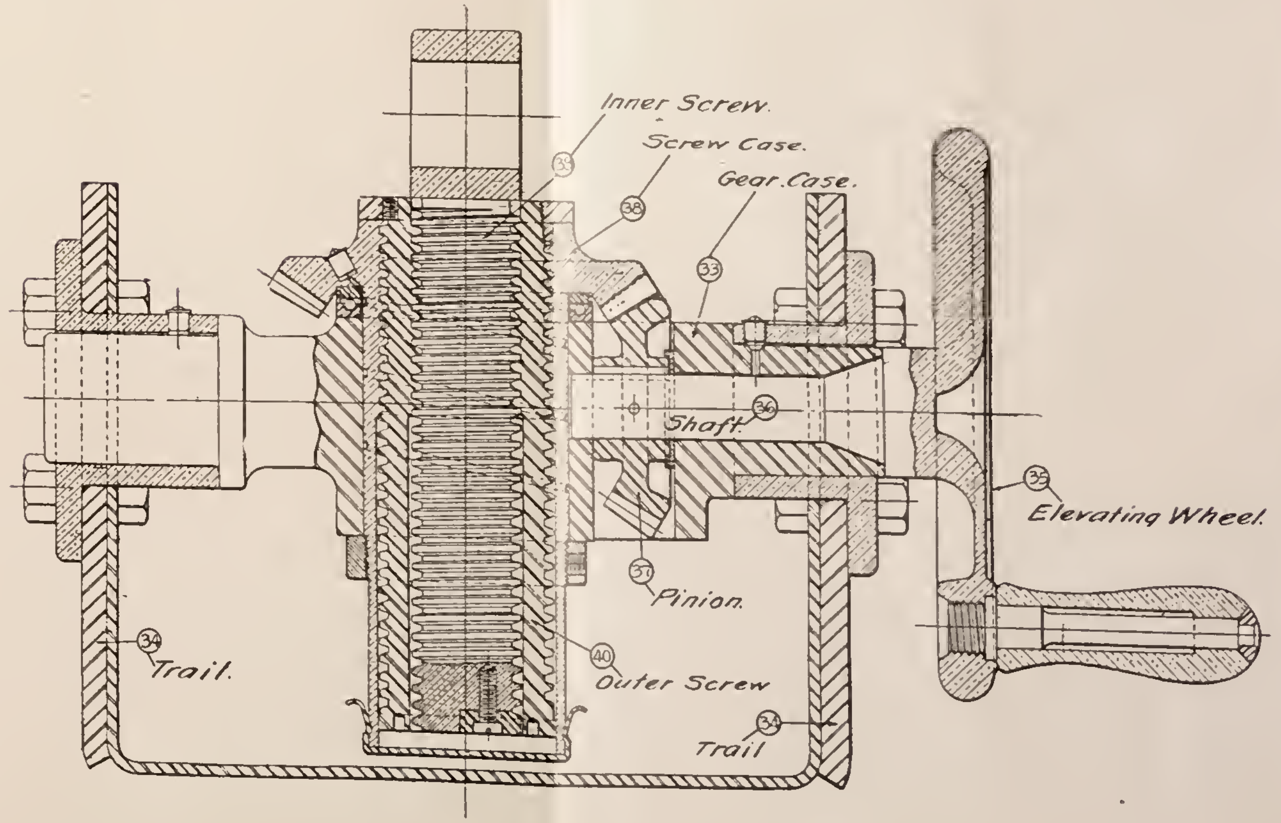


Fig. 4.

3-INCH LANDING GUN MARK IV, WITH CARRIAGE.

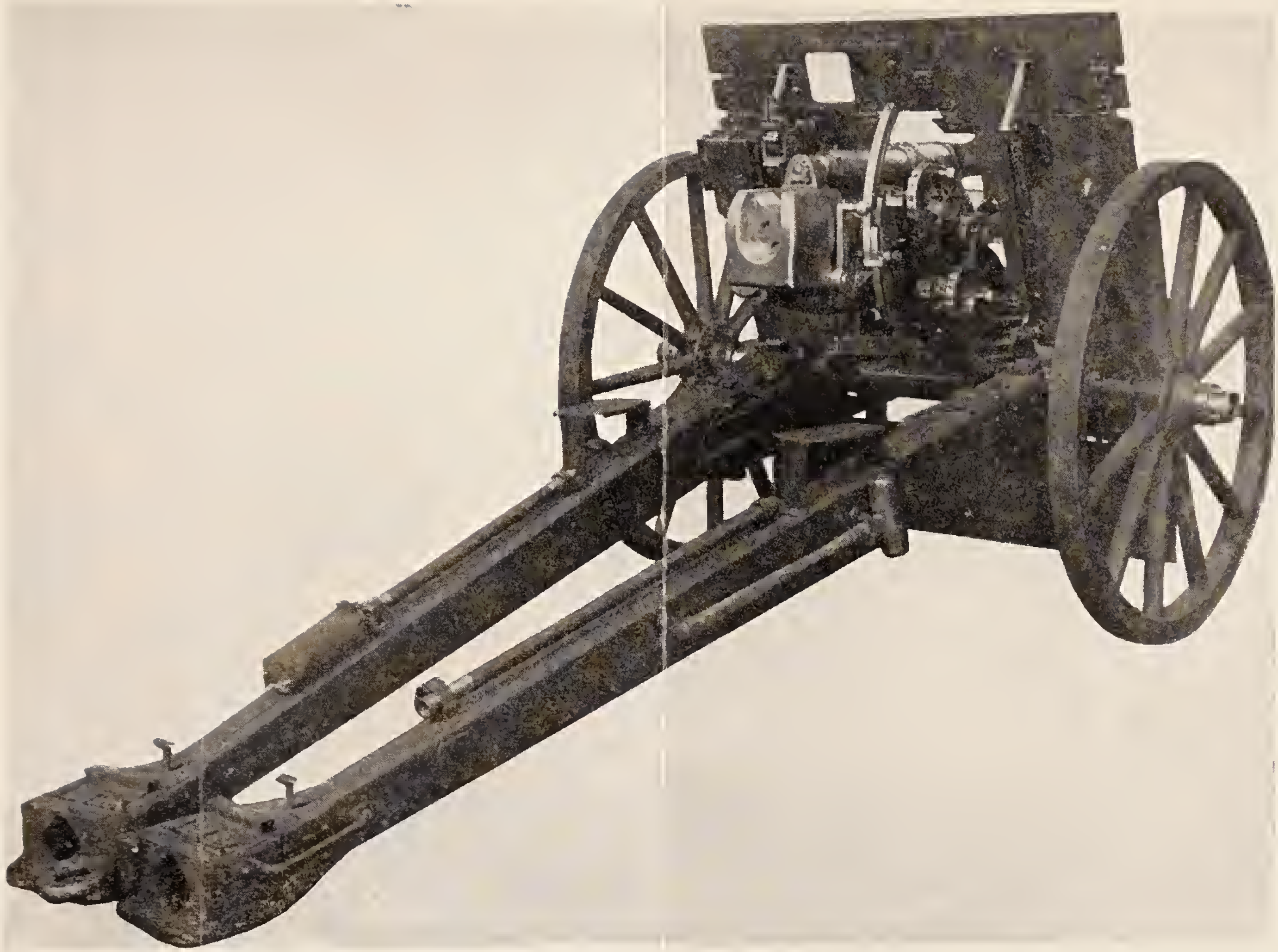


Fig. 1.—3-Inch 23-Caliber High-Angle Landing Gun.

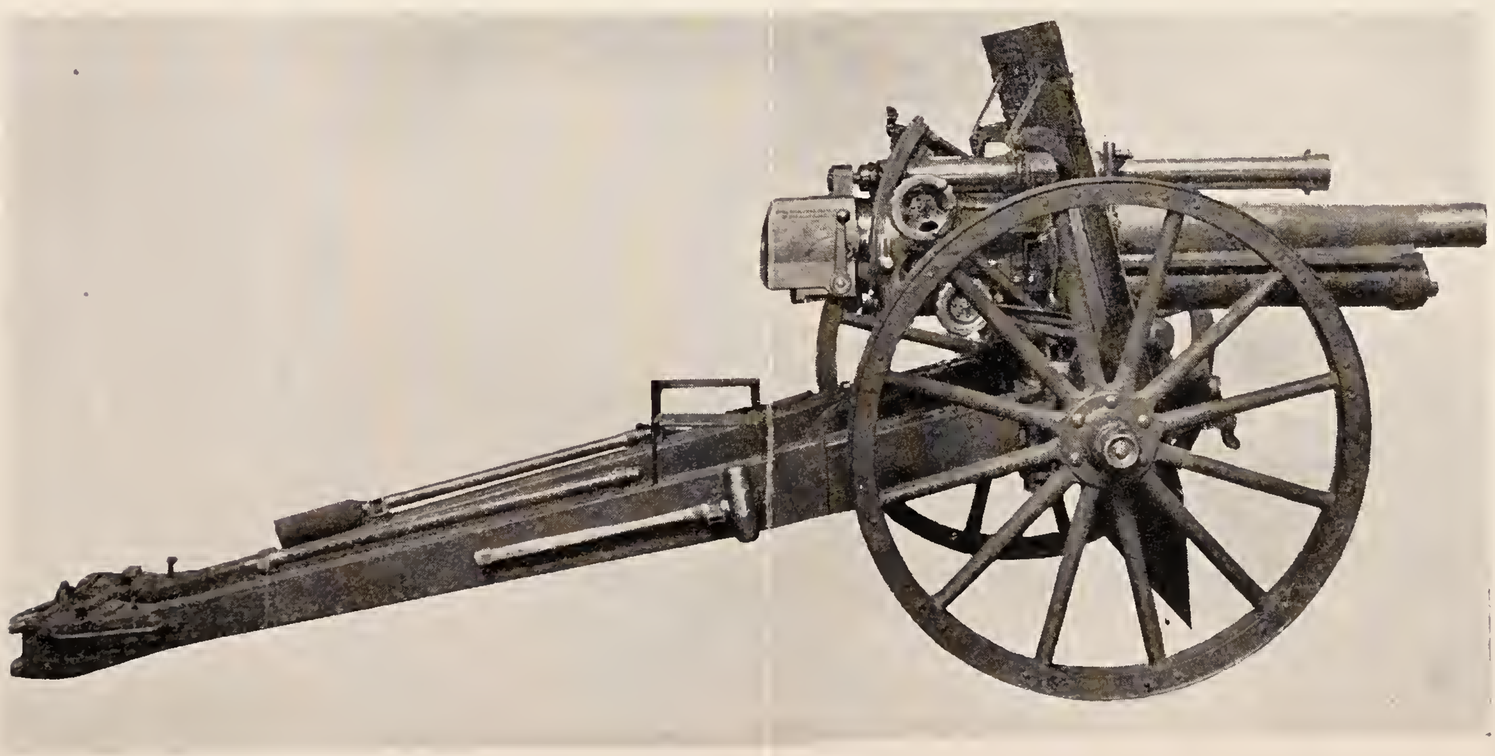


Fig. 2.—3-Inch 23-Caliber High-Angle Landing Gun.

elevation. It is fitted with a *panoramic sight* to be used for indirect fire. This sight is a vertical telescope so fitted with reflecting prisms that the pointer, with his eye at the eye-piece, which is fixed in a horizontal position, may bring into the field of view an object situated at any point in a plane perpendicular to the axis of the telescope.

Below the gun is located the recoil cylinder. For 0° elevation the normal recoil of the gun is 42 inches. At high angles of elevation, however, this recoil must be shortened to prevent the breech of the gun from striking the ground. This is accomplished by decreasing, at high angles of elevation, the available port area through which the recoil liquid can escape during recoil. A special gear is provided that automatically blanks off a certain number of escape ports as the gun is elevated. The result is that the gun is checked with greater force, and comes to rest in a shorter space.

Above the gun is the *recuperator* which returns the gun to battery. No counter-recoil springs are provided at all. The recuperator, to all intents and purposes, is an air compressor. As the gun recoils, the air on one side of the piston becomes highly compressed, with the result that as soon as the rearward motion is stopped, the air pressure forces the gun back to battery.